OVERHEAD POWER LINES

ELEMENTARY DESIGN AND CALCULATIONS

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If R_t, L_t, X_t and Z_t denote the RESISTANCE INDUCTANCE, REACTANCE AND IMPEDANCE respectively per 1 000 *yards* of *single* conductor, then the

$$\text{INDUCTANCE, } L_t = (\cdot 421 \log \frac{S}{r} + \cdot 0457\,\mu) \text{ mH.}$$

$$\text{REACTANCE, } X_t = 2\pi f L_t.$$

f, the frequency, is taken as 50 in all calculations in this chapter. Since the reactance varies with the frequency a correction will have to be applied to all figures given for voltage drop if the system frequency is other than 50

$$\text{IMPEDANCE, } Z_t = \sqrt{R_t^2 + X_t^2}.$$

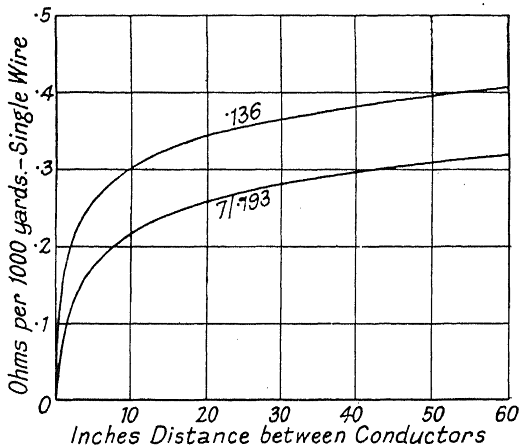


FIG. 1.—Variation of reactance with spacing.

To simplify matters attention will be confined mainly to the consideration of eight standard sizes of *Hard Drawn Copper Conductors*, working particulars of which are given in Table I. Values for intermediate sizes can be deduced with sufficient accuracy by interpolation. (The full range of British Standard Solid and Stranded Hard Drawn Copper Conductors is given in B.S. Spec. No. 125.)

The use of other conductor materials is discussed in Chapter X., page 183.

The values of R_t in Table I. are taken from the standard specification, and those of X_t have been evaluated from the formula given above for a spacing of 3 feet and a frequency of 50 cycles per second.

Assuming a constant value for the reactance greatly simplifies

TABLE I.—*Particulars of Hard Drawn Copper Conductors.*

	Standard Size.	Overall Diameter.	Cross-section.	Resistance per 1000 yards.	Reactance per 1000 yards 50 cycles.	Weight per foot Run.	Safe Working Stress.	Safe Working Load.	Weight of Ice.		Weight of Wire + Ice.		Overall Diameter Wire + Ice.		Wind Load.		Total Load $\sqrt{w^2+p^2}$.		Oblique Sag at 22° F.		Critical Temp.	
									3/8″.	3/16″.	3/8″.	3/16″.	3/8″.	3/16″.	3/8″.	3/16″.	3/8″.	3/16″.	3/8″.	3/16″.	3/8″.	3/16″.
		Ins.	Sq. Ins.	Ohms.	Ohms.	Lb.	Lb. per sq. in.	Lb.	Lb. per foot.	Lb. per foot.	Lb. per foot.	Lb. per foot.	Ins.	Ins.	Lb. per foot.	Lb. per foot.	Lb. per foot.	Lb. per foot.	Feet.	Feet.	°F.	°F.
S.W.G.		d_0	a	R_t	X_t	w_0	S_m	T_m	w_i	w_i	w	w	d	d	p	p	W	W	D_m	D_m		
10	·136	·136	·01453	1·72	·375	·056	31 400	456	·240	·076	·296	·132	·886	·511	·591	·341	·66	·365	1·81	1·00	195	182
8	·162	·162	·02061	1·21	·365	·0794	30 600	633	·252	·082	·331	·161	·912	·537	·608	·358	·69	·39	1·36	·77	185	169
6	·193	·193	·02926	·86	·355	·1127	29 900	874	·266	·089	·379	·202	·943	·568	·629	·378	·73	·43	1·045	·615	174	155
3.	3/·147	·317	·05	·50	·335	·2002	29 200	1457	·321	·118	·521	·318	1·067	·692	·710	·461	·88	·56	·755	·48	158	135
1	3/·18	·388	·075	·33	·325	·3001	28 300	2125	·354	·135	·654	·435	1·138	·763	·758	·509	1·00	·67	·59	·395	141	116
	7/·136	·408	·10	·25	·315	·399	29 350	2935	·363	·139	·762	·538	1·158	·783	·771	·521	1·08	·75	·46	·32	133	105
	7/·166	·498	·15	·168	·305	·595	28 500	4265	·404	·161	·999	·756	1·248	·873	·832	·581	1·30	·95	·38	·28	115	86
	7/·193	·579	·20	·124	·295	·803	28 200	5635	·441	·179	1·244	·982	1·329	·954	·885	·636	1·53	1·17	·34	·26	103	75

The *Resistance* is rounded off a little on the high side.
Reactance is for 3 *feet spacing*.
Oblique Sag is for basic loading conditions and span length 100 feet. This sag is directly proportional to square of span length.
The figures in columns 2, 3, 4, 6 and 7 have been abstracted by permission of the British Engineering Standards Association from British Standard Specification No. 125 for Hard Drawn Copper Conductors (see p. vii).

the calculations and it will be clear from Fig. 1 that no serious erro is involved in so doing since in the short span construction con sidered in this book the spacing will never exceed 5 feet.

A copper conductor of diameter 0·162 inches (0·0201 sq. in.) i the smallest allowed by the E.C. Regulations for O.H. lines in thi country, and the stranded conductor 7/·193 (0·2 sq. in.) is the larges which is, as a rule, justifiable economically. This will be clear fron Fig. 2 which shows how the values of *R*, *X* and *Z* vary with th cross-section. There is obviously little advantage in using conductor larger than 0·15 to reduce voltage drop, owing to the swamping effec

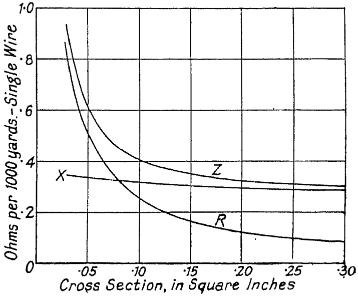


FIG. 2.—Variation of *R*, *X* and *Z* with cross-section.

of the reactance. This limitation does not, of course, apply to under ground cables in which the conductors are much closer together.

Calculation of Voltage Regulation.—The vector diagran in Fig. 3 will be found useful in enabling us to visualise how th various factors involved are related to one another.

OI = current vector = vector of reference.
Cos ϕ = power factor of load.
OE = transmission voltage.
OV = delivery voltage.
$OR = VA$ = resistance drop (RI) parallel to OI.
$OX = AE$ = reactance drop (XI) perpendicular to OI.
$OZ = VE$ = impedance drop.
$PE = OE - OV$ = LINE VOLTAGE DROP.

It is important not to confuse the impedance drop (VE) with the true Line Voltage Drop (PE), which is the arithmetical difference between OE and OV.

The Voltage Regulation is defined as the ratio $\frac{PE}{OV}$.

The Percentage Voltage Regulation $= \frac{PE}{OV} \times 100$ per cent.

Vectors are shown for power factors 0·8 *lagging*, unity and 0·8 *leading*. $OV = 10$ units, and to the same scale $RI = 2$ and $XI =$

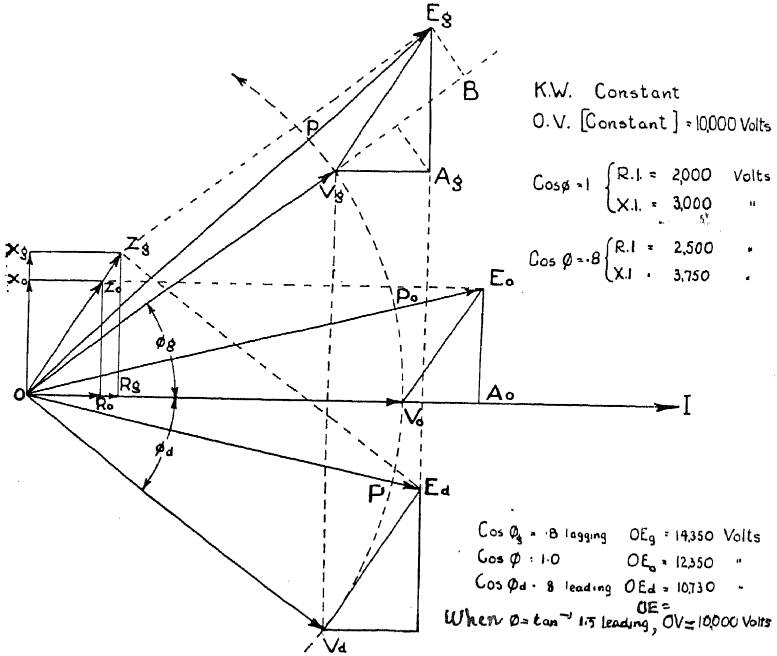


Fig. 3.—Transmission line vector diagram.

3 units at unity P.F., the values at 0·8 P.F. are therefore 2·5 and 3·75 respectively. For clearness, these values of RI and XI are much exaggerated. In practice the impedance drop seldom exceeds 10 % of the delivery voltage.

From the geometry of the figure we have $OE^2 = (OV \cos \phi + RI)^2 + (OV \sin \phi + XI)^2$.

If the current leads on the voltage, ϕ must be taken as negative,

in which case, although $\cos\phi$ remains positive, $\sin\phi$ becomes negative.

This expression is rather cumbersome for general use, but the following simpler formula gives results sufficiently accurate for most practical purposes with a lagging power factor.

$$OE = OV + RI\cos\phi + XI\sin\phi.$$

This is deduced as follows :—

Draw EB perpendicular to OV produced. Then VB is approximately equal to PE.

But
$$\begin{aligned} VB &= VA\cos\phi + AE\sin\phi \\ &= RI\cos\phi + XI\sin\phi. \end{aligned}$$

The results obtained by this simpler formula are exactly correct for one value of ϕ only with each size of conductor, *viz.*,

$$\phi = \tan^{-1}\frac{X}{R},$$

but over the usual range of lagging power factors the error introduced by its use is always inappreciable. For leading power factors, however, it is necessary to use the more exact formula with $\sin\phi$ negative.

If R and X are values for a single conductor, then the *total* line voltage drop will be as follows :—

$$\text{SINGLE-PHASE : V.D.} = 2(RI\cos\phi + XI\sin\phi)$$
$$\text{THREE-PHASE : V.D.} = \sqrt{3}(RI\cos\phi + XI\sin\phi)$$

In a simple length of 3-phase line without branches,

$$\text{Watts delivered} = W = \sqrt{3}VI\cos\phi$$

$$\therefore I = \frac{W}{\sqrt{3}\,.\,V\,.\,\cos\phi}.$$

If this value of I is substituted in the equation for voltage drop we have

$$\begin{aligned} \text{V.D.} &= \frac{\sqrt{3}\,.\,W}{\sqrt{3}\,.\,V\,.\,\cos\phi}(R\cos\phi + X\sin\phi) \\ &= \frac{W}{V}(R + X\tan\phi). \end{aligned}$$

Assuming $KW = 100$, $V = 10\,000$, $f = 50$, balanced load and an equilateral triangle conductor spacing of 3 feet, we get

$$\text{V.D. per mile} = \frac{100\,000 \times 1{\cdot}76}{10\,000}(R_t + X_t \tan\phi)$$
$$= 17{\cdot}6(R_t + X_t \tan\phi).$$

The curves in Fig. 4 have been plotted to illustrate the ADVERSE

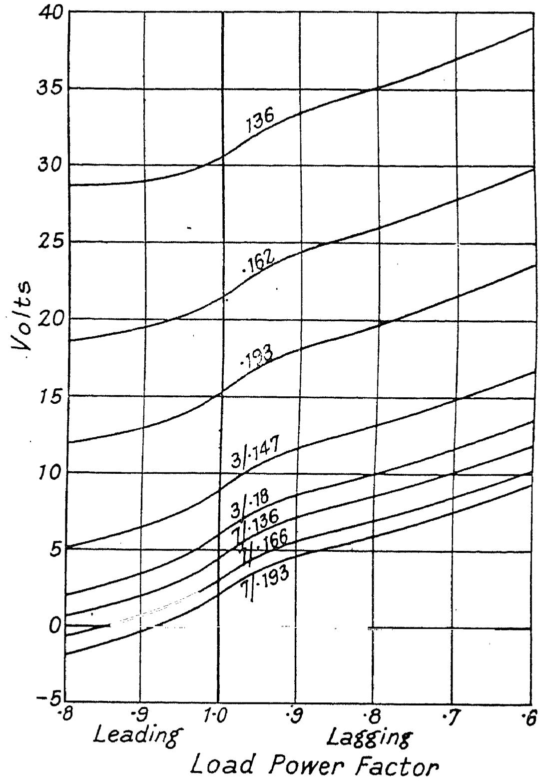


FIG. 4.—Volts drop per 100 K.W. per mile. 10 000 volts, 3-phase, 50 cycles, 3 ft. spacing. Showing effect of power factor.

EFFECT OF LOW LAGGING POWER FACTOR ON VOLTAGE REGULATION. The values for R_t and X_t being per 1 000 yards of single conductor, taken from Table I.; the effect will be seen to be more serious with the larger conductors.

It will be noted, however, that the introduction of a leading current at the delivery end of the line by means of condensers or

over-excited synchronous machinery will reduce the line voltage drop. In certain circumstances it may pay to put in apparatus to take sufficient leading current to reduce the line drop to zero or even to produce a rise of volts in the line. This will be seen from Fig. 4 to be quite practicable with the larger conductors.

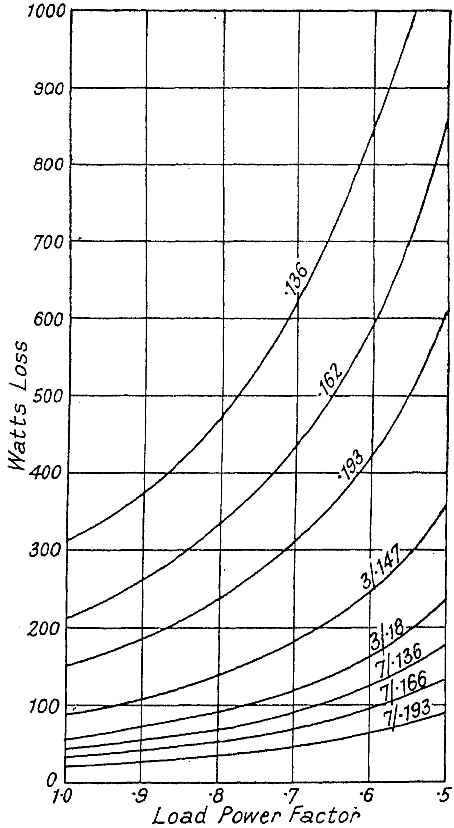


FIG. 5.—Energy loss per 100 K.W. per mile. 10 000 volts, 3-phase, 50 cycles. Showing effect of power factor.

Energy Loss in Conductors.—Although the voltage regulation will usually be the determining factor in the lines under consideration, it is desirable to know approximately the energy loss that will occur in the conductors. The percentage energy loss is generally somewhat greater than the percentage voltage drop, the two values being approximately equal when the load power factor is unity.

The *Total Energy Loss* in a 3-phase system $= 3 \,.\, I^2 \,.\, R$

$$= 3\left(\frac{W}{\sqrt{3}\,.\,V\,.\cos\phi}\right)^2 R$$

$$= \left(\frac{W}{V}\right)^2 \cdot \frac{R}{\cos^2\phi},$$

R being as before the resistance of a single conductor.

The energy loss is therefore inversely proportional to the *square* of the power factor.

Taking the same load conditions as those assumed in Fig. 4, we get :—

Energy Loss per Mile

$$= \left(\frac{100\,000}{10\,000}\right)^2 \times 1{\cdot}76 \times \frac{R_t}{\cos^2\phi} = 176\,.\frac{R_t}{\cos^2\phi} \text{ watts.}$$

The curves in Fig. 5 have been plotted from this formula to illustrate the Adverse Effect of Low Power Factor on the efficiency of transmission.

Power Factor Correction.—The importance of high power factor will be realised from the above, the cost of the conductors depending upon K.V.A. and *not* K.W. An equitable charge to power consumers can, therefore, only be made on a K.V.A. basis. Such a tariff will usually influence them to install apparatus for power factor correction with advantage to all concerned.

Working Curves for V.D. and Energy Loss.—A number of charts will now be given to facilitate the selection of the nearest standard conductor to satisfy a given set of conditions. It will be sufficient for practical purposes to design for a load power factor of 0·8. This should usually give a safe margin, as during the lighting hours, when the problem of voltage regulation is most acute, the P.F. should be much higher than this.

A delivery voltage of 10 000 will be assumed, *i.e.* the current taken in the calculations will be the largest experienced per K.V.A. on a standard 11 000 volt system.

Voltage Drop per Mile (Fig. 6).—Since the V.D. is proportional to the current, and the current (at constant P.F.) is proportional to the K.V.A., the curve connecting V.D. and K.V.A. will be a straight line.

If the load is 500 K.V.A. at 0·8 P.F.,

then V.D. per 1 000 *yards*

$$= \sqrt{3} \, . \, I \, . \, (R_t \cos \phi + X_t \sin \phi)$$

and V.D. per mile

$$= \sqrt{3} \times \frac{500\,000 \times 1{\cdot}76}{\sqrt{3} \times 10\,000 \times {\cdot}8} \times ({\cdot}8R_t + {\cdot}6X_t)$$
$$= 110({\cdot}8R_t + {\cdot}6X_t),$$

R_t and X_t being values per 1 000 yards, obtained from Table I. *E.g.* for ·193 conductor, $R_t = {\cdot}86$ and $X_t = {\cdot}355$ ∴ V.D. per mile = 110 (·8 × ·86 + ·6 × ·355) = 99 volts.

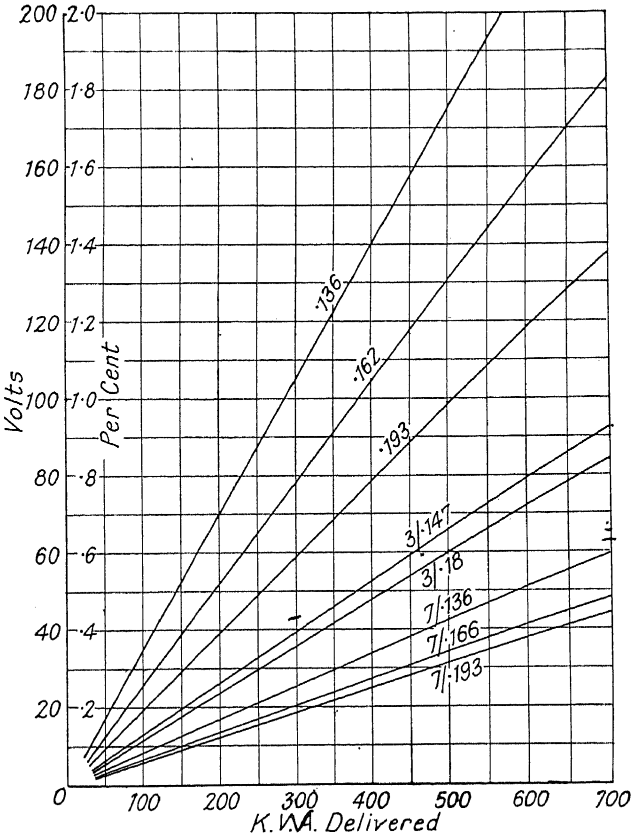


FIG. 6.—Voltage drop per mile. Balanced load. 10 000 volts, 0·8 P.F., 3-phase, 50 cycles, 3 ft. spacing.

This point is plotted in Fig. 6, and a straight line drawn through it from the origin. Straight lines for the other seven selected conductors are drawn similarly.

The *Percentage Voltage Drop* can be read off the same chart.

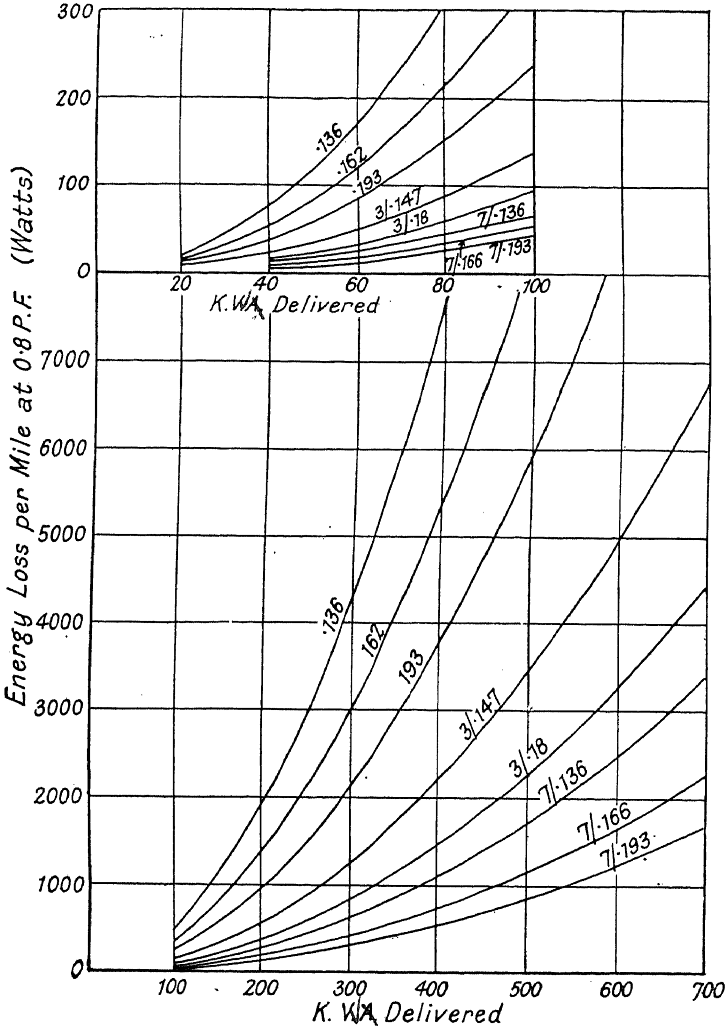


FIG. 7.—Energy loss per mile. Balanced load. 10 000 volts, 0·8 P.F., 3-phase, 50 cycles.

ENERGY LOSS PER MILE (Fig. 7).—If K denotes the K.V.A. delivered, then

$$I = \frac{1\,000K}{\sqrt{3} \times 10\,000 \times \cdot 8} = \frac{K}{8\sqrt{3}} \text{ amps at } 0{\cdot}8 \text{ P.F.}$$

$\therefore$ Energy loss per mile $= 3 \,.\, I^2 \,.\, 1{\cdot}76 \,.\, R_t$

$$= \frac{3 \,.\, K^2 \,.\, 1{\cdot}76 \,.\, R_t}{192},$$

$$= \cdot 0275 \,.\, R_t \,.\, K^2;$$

e.g. for $\cdot 193$ conductor $R_t = \cdot 86$ ohm;

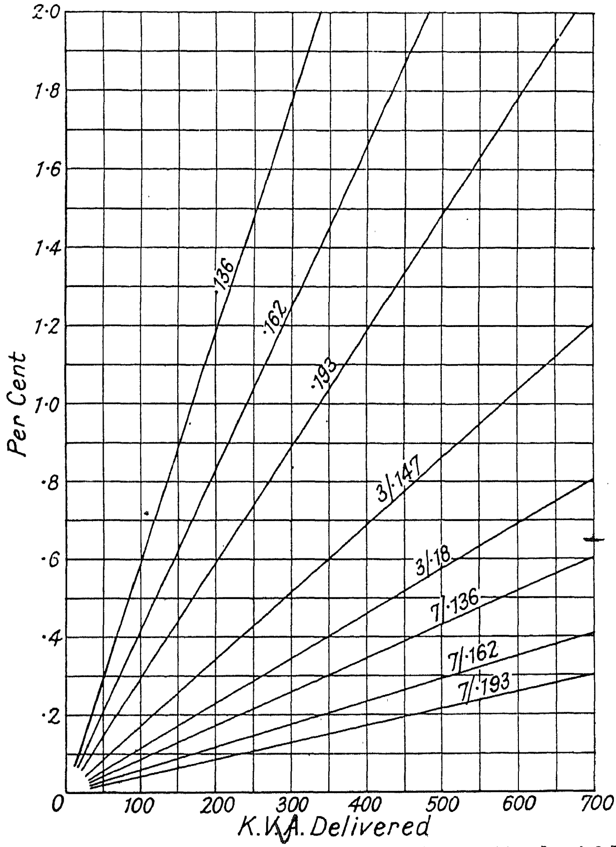


FIG. 8.—% Energy loss per mile. Balanced load. 10 000 volts, 0·8 P.F. 3-phase, 50 cycles.

and if $K = 100$ K.V.A., energy loss per mile

$$= \cdot 0275 \times \cdot 86 \times 100^2$$
$$= 236 \cdot 5 \text{ watts}$$

and so on. Proceeding in this way we are able to plot the curves shown in Fig. 7.

% Energy Loss per Mile (Fig. 8).

$$\text{The } \textit{Energy Loss per mile} = \cdot 0275\ R_t K^2 \text{ watts.}$$
$$\text{The } \textit{Energy Delivered} = 1\,000\ .\ K\ .\ \cos\phi \text{ watts.}$$
$$\%\ \textit{Energy Loss per Mile} = \frac{\cdot 0275\ .\ R_t\ .\ K^2}{1\,000\ .\ K\ .\ \cos\phi} \times 100\ \%$$
$$= \cdot 00344\ .\ R_t\ .\ K\ .\ \%.$$

This is also the equation to a straight line, therefore the % loss need only be calculated for one value of the load with each size of conductor.

Using ·193 conductor for 500 K.V.A.

% Energy loss per mile = ·00344, ·86 . 500 = 1·48 %.

This point is plotted in Fig. 8 and a straight line drawn through it from the origin. Curves for the other conductors are drawn in a similar manner.

% V.D. and Energy Loss at other Voltages.

% V.D.

For a given conductor and load P.F. $\text{V.D.} \propto I$.

If the K.V.A. is constant, $I \propto \frac{1}{V}$.

$\therefore$ V.D. $\propto \frac{1}{V}$ and the % V.D. $\propto \frac{1}{V^2}$.

% Energy Loss.

For a given conductor, energy loss $\propto I^2$.

If the K.V.A. is constant, and also the P.F., $I \propto \frac{1}{V}$,

$$\therefore\ \%\ \text{Energy loss} \propto \frac{1}{V^2}.$$

We see, therefore, that both % voltage drop and the % energy loss are inversely proportional to the *square* of the working voltage. At 6 000 volts, the values are $\left(\frac{10\,000}{6\,000}\right)^2 = 2 \cdot 78$ times the value at 10 000 volts and at 20 000 volts, the values are only one quarter as great.

station is of the order 50 to 100 K.V.A. for distribution to small consumers, feeding an area of a few hundred yards' radius only.

Consumers taking 50 K.V.A. or more should be given a H.V. supply direct.

The principles already given for deciding the size of conductor for H.V. lines apply equally to L.V. lines, but in new work the standard 400/230 volts, 4 wire, 3-phase system should always be adopted.

The neutral conductor should be equal in size to the line conductors, the neutral drop being always appreciable owing to the impossibility of maintaining a balanced load.

CHAPTER II.

CONDUCTORS, SAG AND STRESS CALCULATIONS.

THE true shape of the curve formed by a uniformly loaded wire strung between two supports is a Catenary, but when the ratio of span (L) to sag (D) is large (say) greater than 10 to 1, it is sufficiently accurate for practical purposes to assume that it is a parabola, and the calculations are thereby much simplified.

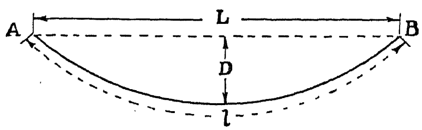


FIG. 10.

The fundamental span formulæ are (Fig. 10)

$$D = \frac{WL^2}{8T} \quad . \quad . \quad . \quad . \quad (1)$$

$$l = L + \frac{8D^2}{3L} \quad . \quad . \quad . \quad . \quad (2)$$

D = sag at middle of span in feet.
L = length of span in feet.
l = length of wire in span in feet.
W = total loading of wire in pounds per foot run.
T = horizontal tension in wire at centre of span in pounds (assumed uniform throughout the span).

It is unnecessary to distinguish between l and L when calculating voltage drop and measuring up length of wire required.

The actual tension in the wire is not exactly uniform throughout the span, but gradually increases towards the supports where it has the maximum value $\sqrt{T^2 + \left(\frac{WL}{2}\right)^2}$. For the ratios of span length to sag recommended in this book it will be found that the maximum

tension is only a fraction of 1 % greater than the horizontal tension, and therefore the discrepancy may be safely neglected.

The total loading W, which produces the tension T, comprises:

1. The dead weight of the wire.
2. The weight of any ice, sleet or snow that may cling to the wire.
3. Wind pressure.

Basic Conditions of Stress.—In order to ensure that a reasonable factor of safety is allowed for in erecting the conductors, the Electricity Commissioners have laid down the Basic Loading Conditions to be assumed (see E.C. Regulations, Appendix I.).

For High Voltage Lines (above 650 volts) these are as follows:

Temperature.—22° F.
Ice Loading.—$\frac{3}{8}$ inch radial thickness.
Wind Pressure.—8 lb. per square foot horizontally at right angles to the line on whole diameter of ice covered conductor.
Factor of Safety.—2, based on the breaking stress given in B.S. Spec. 125 for hard drawn copper conductors.

For Low Voltage Lines.—In order to permit a lower *real* factor of safety the hypothetical ice loading is reduced to $\frac{3}{16}$ inch. All other basic loading conditions are the same as for high voltage lines.

It may be remarked that the above figures for temperature, ice loading and wind pressure are supposed to represent the worst weather conditions likely to be experienced simultaneously in Great Britain, and are legally applicable in this country only.

In tropical countries it will be possible to work with smaller sags owing to the absence of ice, but it must not be overlooked that the wind pressures experienced are frequently greater than in this country.

Minimum Sag under Basic Loading Conditions.—The starting-point in the sag and stress calculations, is to find the minimum sag which must be allowed to ensure that the safe maximum stress is not exceeded under the worst loading conditions.

Constants for the eight standard conductors under consideration are given in Table I., page 4, the notation being as follows (see Fig. 11):—

d_0 = diameter of conductor in inches (B.S. Spec. 125).
t = thickness of ice coating in inches ($\frac{3}{8}$ inch for H.V., $\frac{3}{16}$ inch for L.V. lines).
$d = d_0 + 2t$ = diameter of ice-covered conductor in inches.
w_0 = weight of conductor in pounds per foot run (B.S. Spec. 125).
$w_i = 1{\cdot}25t(d_0 + t)$ = weight of ice in pounds per foot run.
This assumes weight of ice as 57·3 lb. per cubic foot; E.C. Regulations specify 57 lb.
$w = w_0 + w_i$ = total *vertical* load in pounds.
$p = \frac{Pd}{12} = \frac{8d}{12} = \frac{2}{3}d$ = wind load in pounds per foot run (acting horizontally).
$W = \sqrt{w^2 + p^2}$ = total load on conductor in pounds per foot run.

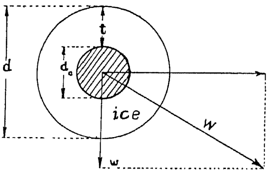


FIG. 11.

Sag and Tension for Erection Purposes.—The weather conditions at the time of erection are very different from those producing the maximum stress and it is therefore necessary to determine what tension and sag should be allowed when the wire is erected in still air at various temperatures in order that the maximum stress shall not exceed the safe limit under the basic loading conditions. Perhaps it should be explained that considerations of pole sizes and conductor spacings demand generally that the sag of the conductors should be as small as possible. The smaller the sag the lower the *F* of *S*, hence the necessity for a legal limit.

The calculations are somewhat involved since expansion due to increase of temperature is accompanied by contraction due to elasticity.

The simplest form of these calculations will now be given.

Critical Temperature.—Starting from 22° F. with ice loading, as the temperature rises, the wire elongates and the sag increases up

to 32° F., when the reduction in loading due to the melting of the ice results in contraction due to elasticity. As the temperature continues to rise the sag increases again until at a certain temperature the sag has again the same value that it had originally under the basic loading conditions at 22° F. The temperature at which this occurs is called the "Critical Temperature," the conception being of great use in solving sag and stress problems in overhead line conductors.

Let D_m, S_m and T_m denote the sag, stress and tensile load respectively under the basic loading conditions and D_c, S_c and T_c the values at the critical temperature.

Then $$D_c = D_m = \frac{WL^2}{8T_m} = \frac{w_0 L^2}{8T_c},$$

$$\therefore\ T_c = \frac{w_0}{W} \cdot T_m, \quad \text{and } S_c = \frac{w_0}{W} \cdot S_m.$$

Let θ_c denote the critical temperature,

K the coefficient of linear expansion per deg. F. $= 9{\cdot}222 \times 10^{-6}$ (B.S.S. 125),

and M the modulus of elasticity in pounds per square inch $= 18 \times 10^6$ (B.S.S. 125).

Then the elongation due to temp. rise $= l \,.\, K \,.\, (\theta_c - 22)$

and the contraction due to elasticity $= (S_m - S_c)\dfrac{l}{M}$.

These values are equal; therefore, equating one to the other we get

$$\theta_c - 22 = \frac{S_m}{K \,.\, M}\left(1 - \frac{w_0}{W}\right) = \frac{S_m}{166}\left(1 - \frac{w_0}{W}\right),$$

from which θ_c can be calculated.

For example, substituting the known values for ·05 square inch copper from Table I. for H.V. lines we get

$$\theta_c - 22 = \frac{29\,200}{166}\left(1 - \frac{\cdot 2}{\cdot 88}\right) = 136,$$

$$\therefore\ \theta_c = 136 + 22 = 158^\circ \text{ F.}$$

Values of θ_c are given in Table I, page 4.

To Find Sag and Tension to be Allowed on Erection.—*Decrease in Length* due to fall in temp. from θ_c to some other temp. θ,

$$= l_c K(\theta_c - \theta),$$

l_c being the length of wire in span at the critical temp.

For the unloaded wire in still air, T.D. $= \frac{w_0 L^2}{8}$ which is constant for one particular length of span and size of conductor.

$$\text{T.D.} = T_c D_c$$
$$\text{and S.D.} = S_c D_c$$

T, D and S being values for temp. θ.

Increase in length due to increased tension

$$= \frac{l_c}{M}(S - S_c) = \frac{l_c S_c}{M}\left(\frac{D_c}{D} - 1\right).$$

If l is the length of wire at temp. θ, then

$$l_c - l = L + \frac{8D_c^2}{3L} - \left(L + \frac{8D^2}{3L}\right).$$

This must be equal to the difference between the *increase* in length due to elastic extension and the *decrease* in length due to thermal contraction.

$$\therefore \frac{8}{3L}(D_c^2 - D^2) = l_c K(\theta_c - \theta) - \frac{l_c S_c}{M}\left(\frac{D_c}{D} - 1\right).$$

At this stage no appreciable error is introduced by substituting L for l_c, therefore equation may be written :—

$$\theta_c - \theta = \left(\frac{8D_c^2}{3KL^2}\right) - \left(\frac{8}{3KL^2}\right)D^2 + \frac{\left(\frac{S_c D_c}{KM}\right)}{D} - \left(\frac{S_c}{KM}\right),$$

from which D can be calculated for any values of θ and L. The first step is to find S_c which equals $\frac{w_0 L^2}{8 \,.\, D_c a}$. S_c is independent of the length of span since $D_c \propto L^2$.

Substituting known values for ·05 *square inch copper* (3/·147) (H.V. loading) from Table I., page 4, we get

$$S_c = \frac{\cdot 2 \times 100^2}{\cdot 755 \times 8 \times \cdot 05} = 6\,630 \text{ lb./sq. in.}$$

The following table can now be prepared :—

Span, feet.	D_c.	D_c^2.	$\frac{8}{3KL^2}$.	$\frac{8D_c^2}{3KL^2}$.	$\frac{S_cD_c}{KM}$.	$\frac{S_c}{KM}$.
100	·755	·57	28·92	16·5	30·15	39·94
150	1·70	2·89	12·85	37·1	67·8	39·94
200	3·02	9·1	7·23	65·9	120·6	39·94
250	4·72	22·3	4·63	103·0	188·4	39·94
300	6·79	46·0	3·21	148·3	271·4	39·94

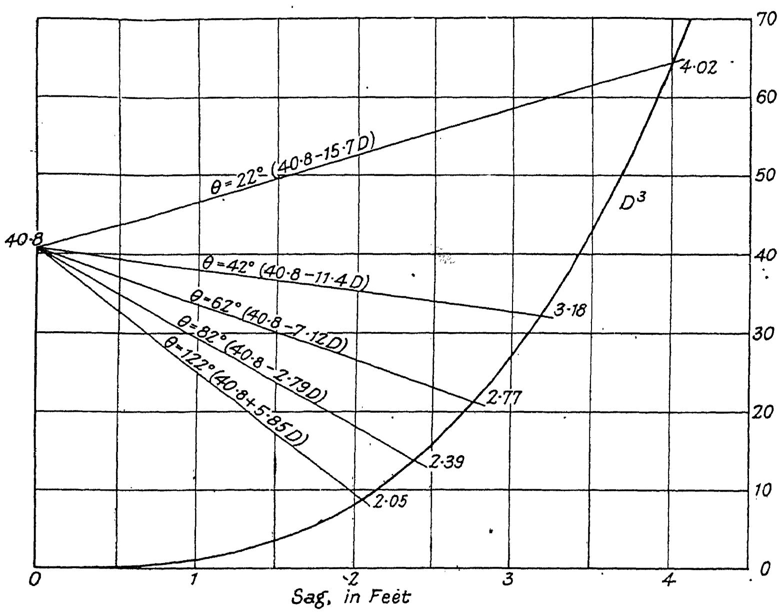


FIG. 12.—Graphic method of solving cubic equations. 3/·147 copper conductor, H.V. loading, 250 ft. span.

Substituting all the known values in equation for D we have for a 250 *feet span*.

$$158 - \theta = 103 - 4{\cdot}63D^2 + \frac{188{\cdot}4}{D} - 39{\cdot}94$$

$$\therefore \theta = 4{\cdot}63D^2 - \frac{188{\cdot}4}{D} + 94{\cdot}94,$$

e.g. if $\theta = 62°$ we have $4{\cdot}63D^2 - \frac{188{\cdot}4}{D} + 32{\cdot}94 = 0$

i.e. $D^3 = 40{\cdot}8 - 7{\cdot}12D$ and $D = \underline{2{\cdot}765 \text{ feet}}$.

TABLE II.—*Hard Drawn Copper Conductors. Sags in Still Air for Erection Purposes. High Voltage Lines ($\frac{3}{8}$-in. Ice).*

Span in Feet.	Temp. Faht.	·162.	·193.	3/·147.	3/·18.	7/·136.	7/·166.	7/·193.
	Sq. ins.	·02061	·02926	·05	·075	·10	·15	·20
		feet.	feet.	feet.	feet.	feet.	feet.	feet.
150	122	2·25	1·57	1·19	1·06	0·92	0·92	0·92
	82	1·66	1·02	0·78	0·71	0·63	0·62	0·63
	62	1·37	0·83	0·65	0·60	0·53	0·53	0·54
	42	1·10	0·68	0·55	0·51	0·46	0·46	0·47
	22	0·87	0·57	0·48	0·44	0·44	0·40	0·41
	22	*3·06*	*2·34*	*1·70*	*1·33*	*1·035*	*·855*	*·765*
200	122	4·62	3·35	2·38	1·99	1·66	1·62	1·58
	82	4·04	2·64	1·70	1·40	1·18	1·15	1·12
	62	3·72	2·26	1·42	1·18	1·01	0·98	0·97
	42	3·40	1·92	1·20	1·01	0·87	0·86	0·85
	22	3·04	1·61	1·02	0·88	0·77	0·75	0·75
	22	*5·44*	*4·18*	*3·02*	*2·36*	*1·84*	*1·52*	*1·36*
250	122	7·69	5·70	4·02	3·29	2·66	2·51	2·45
	82	7·14	4·99	3·18	2·49	1·97	1·95	1·80
	62	6·83	4·60	2·77	2·14	1·70	1·57	1·57
	42	6·53	4·19	2·39	1·83	1·47	1·39	1·37
	22	6·22	3·78	2·05	1·59	1·29	1·23	1·21
	22	*8·50*	*6·53*	*4·72*	*3·69*	*2·875*	*2·38*	*2·12*
300	122	11·40	8·58	6·05	4·86	3·87	3·57	3·41
	82	10·88	7·87	5·15	3·92	3·00	2·75	2·62
	62	10·60	7·50	4·69	3·47	2·62	2·40	2·29
	42	10·32	7·11	4·22	3·04	2·30	2·10	2·02
	22	10·03	6·71	3·74	2·65	2·01	1·85	1·79
	22	*12·24*	*9·405*	*6·79*	*5·31*	*4·14*	*3·42*	*3·06*
350	122	—	—	8·50	6·78	5·35	4·84	4·64
	82	—	—	7·58	5·74	4·32	3·92	3·68
	62	—	—	7·10	5·23	3·84	3·40	3·25
	42	—	—	6·60	4·71	3·40	3·01	2·89
	22	—	—	6·10	4·20	2·98	2·67	2·56
	22	—	—	*9·24*	*7·23*	*5·64*	*4·65*	*4·16*
400	122	—	—	11·30	8·93	7·05	6·28	5·92
	82	—	—	10·37	7·87	5·92	5·15	4·82
	62	—	—	9·88	7·30	5·35	4·62	4·32
	42	—	—	9·38	6·73	4·82	4·13	3·86
	22	—	—	8·88	6·16	4·31	3·70	3·46
	22	—	—	*12·08*	*9·44*	*7·36*	*6·08*	*5·44*

Sags under basic loading conditions shown in italics.

TABLE III.—*Hard Drawn Copper Conductors. Tensions in Still Air for Erection Purposes. High Voltage Lines* ($\frac{3}{8}$-*in. Ice*).

Span in Feet.	Temp. Faht.	·162.	·193.	3/·147.	3/·18.	7/·136.	7/·166.	7/·193.
	Sq. ins.	·02061	·02926	·05	·075	·10	·15	·20
		lb.	lb.	lb.	lb.	lb.	lb.	lb.
150	122	99	200	473	795	1 220	1 820	2 460
	82	134	308	722	1 190	1 780	2 700	3 590
	62	163	380	865	1 405	2 120	3 150	4 190
	42	203	462	1 020	1 655	2 440	3 630	4 800
	22	256	550	1 170	1 920	2 740	4 180	5 510
	22	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
200	122	86	168	420	755	1 200	1 840	2 540
	82	99	214	589	1 070	1 700	2 580	3 590
	62	107	249	704	1 270	1 980	3 040	4 140
	42	117	294	833	1 485	2 290	3 460	4 730
	22	131	350	980	1 705	2 600	3 960	5 360
	22	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
250	122	81	155	389	715	1 170	1 850	2 570
	82	87	177	491	945	1 580	2 380	3 490
	62	91	191	564	1 095	1 840	2 950	4 000
	42	95	210	655	1 280	2 120	3 340	4 580
	22	100	233	761	1 475	2 620	3 770	5 180
	22	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
300	122	78	148	372	695	1 160	1 870	2 650
	82	82	161	437	860	1 490	2 430	3 450
	62	84	169	480	975	1 710	2 790	3 950
	42	86	178	533	1 110	1 950	3 190	4 470
	22	89	189	600	1 275	2 230	3 610	5 050
	22	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
350	122	—	—	360	680	1 140	1 880	2 650
	82	—	—	403	800	1 415	2 320	3 340
	62	—	—	431	880	1 590	2 680	3 780
	42	—	—	463	975	1 800	3 020	4 250
	22	—	—	500	1 090	2 050	3 410	4 800
	22	—	—	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
400	122	—	—	355	670	1 135	1 890	2 720
	82	—	—	386	760	1 350	2 310	3 340
	62	—	—	406	820	1 490	2 580	3 720
	42	—	—	428	890	1 660	2 880	4 160
	22	—	—	451	975	1 850	3 220	4 650
	22	—	—	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*

Maximum working tensions allowed by E.C. Regulations shown in italics.

This may be solved by slide rule or graphically as indicated in Fig. 12. In either case a table of cubes of numbers will be found useful.

Having obtained the sag in this way, the tension can easily be found since TD is constant and equal to $\frac{w_0 L^2}{8}$. For 3/·147 at 62° F. we have

$$T = \frac{\cdot 2 \times 250^2}{2\cdot 765 \times 8} = 565 \text{ lbs.}$$

TABLE IV.—*Hard Drawn Copper Conductors. Sags in Still Air for Erection Purposes. Low Voltage Lines ($\frac{3}{16}$-in. Ice).*

Span in Feet.	Temp. Faht.	·136.	·162.	·193.	3/·147.	3/·18.	7/·136.	7/·166.	7/·193.
	Sq. ins.	·01453	·02061	·02926	·05	·075	·10	·15	·20
		feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.
100	122	0·44	0·41	0·39	0·41	0·43	0·39	0·41	0·42
	82	0·28	0·26	0·26	0·27	0·28	0·26	0·27	0·27
	62	0·24	0·22	0·22	0·23	0·23	0·22	0·23	0·23
	42	0·21	0·19	0·19	0·20	0·20	0·19	0·20	0·20
	22	0·18	0·17	0·17	0·18	0·18	0·17	0·18	0·18
	22	*1·00*	*0·77*	*0·615*	*0·48*	*0·395*	*0·32*	*0·28*	*0·26*
150	122	1·37	1·07	0·97	0·94	0·95	0·86	0·89	0·90
	82	0·88	0·70	0·65	0·64	0·64	0·59	0·60	0·62
	62	0·72	0·58	0·55	0·54	0·54	0·51	0·52	0·53
	42	0·60	0·50	0·47	0·47	0·47	0·44	0·45	0·46
	22	0·51	0·44	0·41	0·42	0·42	0·39	0·40	0·41
	22	*2·25*	*1·73*	*1·385*	*1·08*	*0·89*	*0·72*	*·063*	*0·585*
200	122	3·00	2·23	1·88	1·71	1·66	1·49	1·50	1·54
	82	2·28	1·57	1·31	1·21	1·17	1·06	1·07	1·10
	62	1·93	1·32	1·11	1·03	1·00	0·92	0·92	0·95
	42	1·61	1·11	0·95	0·89	0·87	0·80	0·81	0·83
	22	1·34	0·95	0·82	0·78	0·77	0·71	0·71	0·73
	22	*4·00*	*3·08*	*2·46*	*1·92*	*1·58*	*1·28*	*1·12*	*1·04*
250	122	5·21	3·87	3·14	2·73	2·58	2·28	2·27	2·31
	82	4·42	3·03	2·34	2·02	1·90	1·69	1·67	1·71
	62	4·03	2·62	2·00	1·74	1·64	1·46	1·46	1·48
	42	3·61	2·24	1·72	1·51	1·43	1·29	1·28	1·30
	22	3·18	1·92	1·48	1·32	1·25	1·14	1·14	1·16
	22	*6·25*	*4·81*	*3·84*	*3·00*	*2·47*	*2·00*	*1·75*	*1·625*
300	122	7·79	5·95	4·77	4·08	3·69	3·23	3·18	3·19
	82	7·04	5·02	3·82	3·18	2·83	2·46	2·42	2·45
	62	6·64	4·56	3·36	2·78	2·47	2·16	2·12	2·15
	42	6·20	4·08	2·93	2·43	2·16	1·90	1·86	1·89
	22	5·75	3·61	2·55	2·13	1·91	1·70	1·67	1·69
	22	*9·00*	*6·93*	*5·54*	*4·32*	*3·56*	*2·88*	*2·52*	*2·31*

Sags under basic loading conditions shown in italics.

It will be realised from the above example that the calculation of sag and tension is no light task to be undertaken on the spur of the moment. Hence the necessity for working tables. Tables II. and III. give values of sag and tension for *High Voltage* lines ($\frac{3}{8}$-in. ice) and Tables IV. and V. for *Low Voltage* lines ($\frac{3}{16}$-in. ice).

Charts for erection purposes can be prepared from these tables. Curves for 3/·147 (·05 sq. in.) are plotted in Figs. 13 and 14.

TABLE V.—*Hard Drawn Copper Conductors. Tensions in Still Air for Erection Purposes. Low Voltage Lines ($\frac{3}{16}$-in. Ice).*

Span in Feet.	Temp. Faht.	·136.	·162.	·193.	3/·147.	3/·18.	7/·136.	7/·166.	7/·193.
	Sq. ins.	·01453	·02 061	·02926	·05	·075	·10	·15	·20
		lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
100	122	160	245	360	610	870	1 280	1 810	2 390
	82	250	385	540	925	1 350	1 920	2 800	3 600
	62	290	450	640	1 090	1 600	2 220	3 230	4 290
	42	335	525	740	1 250	1 850	2 600	3 720	4 960
	22	390	600	840	1 390	2 060	2 900	4 220	5 580
	22	*456*	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
150	122	115	208	327	600	890	1 300	1 890	2 510
	82	179	318	488	880	1 320	1 900	2 790	3 630
	62	219	385	578	1 040	1 550	2 200	3 210	4 260
	42	263	445	675	1 200	1 790	2 550	3 700	4 900
	22	309	507	775	1 340	2 010	2 870	4 180	5 500
	22	*456*	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
200	122	93	178	300	585	900	1 340	1 980	2 610
	82	123	253	430	825	1 280	1 880	2 780	3 660
	62	145	300	508	970	1 500	2 170	3 200	4 240
	42	174	358	593	1 125	1 720	2 490	3 670	4 850
	22	209	418	688	1 285	1 950	2 810	4 130	5 460
	22	*456*	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
250	122	84	160	280	570	910	1 370	2 040	2 720
	82	99	205	376	775	1 230	1 850	2 770	3 670
	62	108	237	440	900	1 430	2 130	3 170	4 220
	42	121	277	511	1 035	1 640	2 420	3 640	4 820
	22	137	323	595	1 185	1 870	2 740	4 060	5 400
	22	*456*	*633*	*874*	*1 457*	*2 125*	*2 935*	*4 265*	*5 635*
300	122	81	150	266	550	915	1 390	2 100	2 830
	82	90	178	332	705	1 190	1 820	2 760	3 690
	62	95	196	378	810	1 370	2 070	3 150	4 200
	42	102	219	432	925	1 560	2 350	3 610	4 780
	22	110	248	497	1 055	1 760	2 640	4 000	5 350
	22	*456*	*633*	*874*	*1 467*	*2 125*	*2 935*	*4 265*	*5 635*

Maximum working tensions allowed by E.C. Regulations shown in italics.

It will be noted that on the shorter spans the variation of tension with temperature is considerable. The undesirability of using spans of unequal length will be at once clear. If contiguous spans differ very much in length, changes of temperature will cause longitudinal pulls which may result in the conductors slipping at the binders. Variations in span length should not exceed 10 % of the average. The binders will stand up to this difference and the poles are flexible. In cases where abnormally short or long spans are unavoidable, tensioning insulators and longitudinal stays must be used. The remarks in this paragraph do not apply to lines using suspension insulators.

Sag at 122° F. in Still Air (see Figs. 15 and 16).—These curves (plotted from Tables II. and IV.) are required for determining the height of pole required. The Fig. 15 curves also appear in the first quadrant of Chart (Fig. 51, page 101).

It may be worth noting that for conductors up to ·1 sq. in. on H.V. lines and up to ·05 sq. in. on L.V. lines the oblique sag under basic loading conditions is greater than the vertical sag in still air at 122° F.

Sag at 62° F. in Still Air (see Figs. 17 and 18).—These curves (also plotted from Tables II. and IV.) are required when determining the horizontal spacing between conductors, which will shortly be considered.

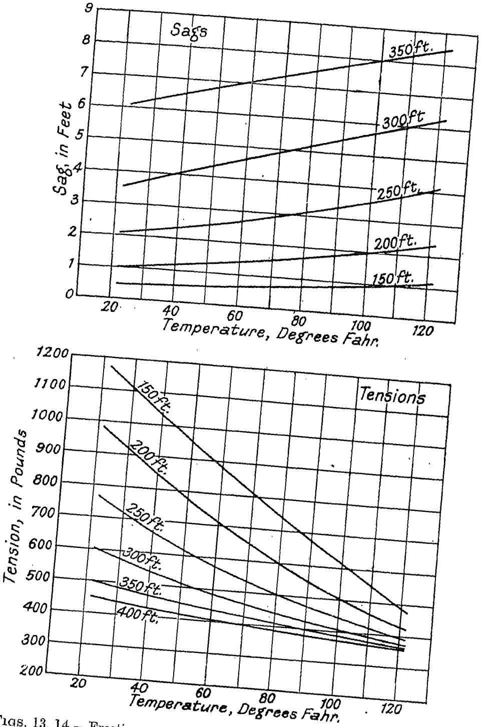
Sag and Tension under various other Loading Conditions.—Although the sag and tension tables given are sufficient for practical purposes, the following calculations will be found interesting and instructive.

Vertical Sag at 22° F. with $\frac{3}{8}$ inch Ice only (no wind).—Let D_m, S_m and W_m refer to basic loading conditions and D_i, S_i and W_i to ice loading only;

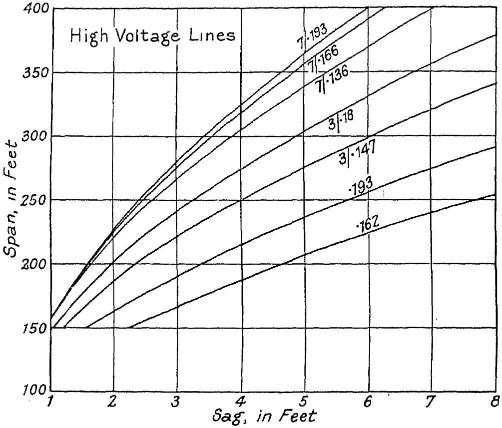
then
$$D_m = \frac{W_m L^2}{8T_m} \text{ and } D_i = \frac{W_i L^2}{8T_i},$$
$$\therefore \frac{D_m}{D_i} = \frac{W_m T_i}{W_i T_m} = \frac{W_m S_i}{W_i S_m}.$$
Whence
$$S_i = S_m \cdot \frac{D_m W_i}{D_i W_m}.$$

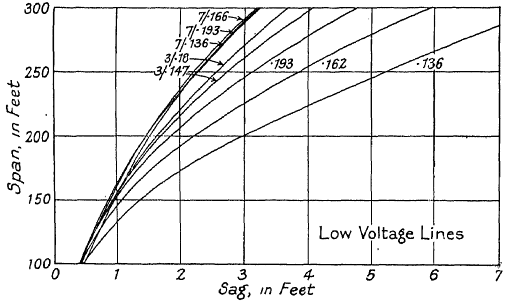
The *Elastic Contraction* due to removal of wind

$$= (S_m - S_i)\frac{l}{M} = \frac{S_m l}{M}\left(1 - \frac{D_m W_i}{D_i W_m}\right).$$

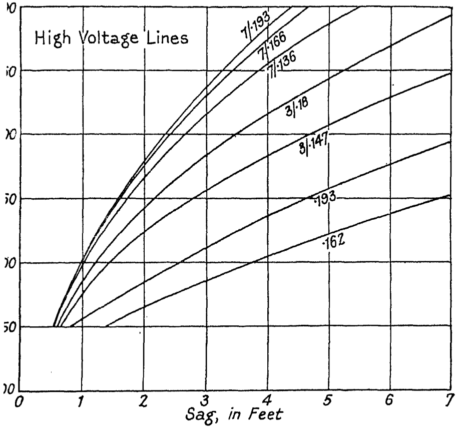


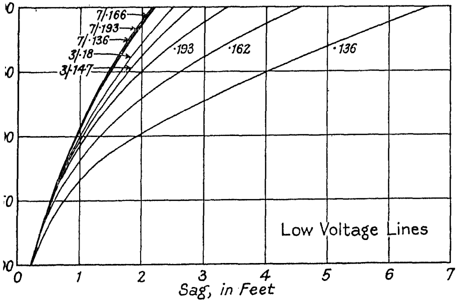
FIGS. 13, 14.—Erection sags and tensions. 3/·147 [·05 sq. in.] copper, high voltage lines.





FIGS. 15, 16.—Sags of copper conductors at 122° F.





Figs. 17, 18.—Sags of copper conductors at 62° F.

This is equal to the change of length of wire in span

$$= l_m - l_i = \frac{8D_m{}^2 - 8D_i{}^2}{3L}.$$

Equating one to the other, and putting L for l, we get

$$D_m{}^2 - D_i{}^2 = \frac{3S_m \,.\, L^2}{8M}\left(1 - \frac{D_m W_i}{D_i W_m}\right).$$

Substituting known values for ·05 sq. in. copper conductor and 250 feet span we get

$$4{\cdot}72^2 - D_i{}^2 = \frac{3 \times 29\,200 \times 250^2}{8 \times 18 \times 10^6}\left(1 - \frac{4{\cdot}72 \times {\cdot}521}{D_i \times {\cdot}88}\right).$$

Whence $\quad D_i{}^3 + 15{\cdot}7D_i - 106{\cdot}3 = 0$

and $\quad D_i = 3{\cdot}66$ feet.

Now $\quad T_i = \frac{W_i L^2}{8D_i} = \frac{{\cdot}521 \times 250^2}{8 \times 3{\cdot}66} = 1\,110$ lb.

$$\therefore S_i = \frac{1\,110}{{\cdot}05} = 22\,200 \text{ lb. / sq. in.}$$

Vertical Sag at 22° F. in Still Air Without Ice.—As above, if D_0, S_0 and W_0 refer to these conditions we have

$$D_m{}^2 - D_0{}^2 = \frac{3S_m L^2}{8M}\left(1 - \frac{D_m W_0}{D_0 W_m}\right),$$

i.e. $\quad 4{\cdot}72^2 - D_0{}^2 = \frac{3 \times 29\,200 \times 250^2}{8 \times 18 \times 10^6}\left(1 - \frac{4{\cdot}72 \times {\cdot}2}{D_0 \times {\cdot}88}\right).$

Whence $D_0{}^3 + 15{\cdot}7D_0 - 40{\cdot}8 = 0$ and $D_0 = 2{\cdot}05$ feet, which agrees with the value given in Table II. which was prepared from equation on page 22.

Vertical Sag at 32° F. with $\frac{3}{8}$-inch Ice only (no wind).—In this case we have

$$\text{Thermal Expansion} = lK(32 - 22) = 10lK.$$

Starting with the ice-loaded conductor at 22° F. in still air, w is constant, therefore

$$S_i D_i = S_{32} D_{32}.$$

Substituting for S_{32} and putting L for l we get

$$\frac{8(D_{32}{}^2 - D_i{}^2)}{3L} = 10KL - \frac{S_i L}{M}\left(1 - \frac{D_i}{D_{32}}\right).$$

Inserting known values

$$D_{32}^2 - 3{\cdot}66^2 = \frac{30 \times 9{\cdot}222 \times 10^{-6} \times 250^2}{8} - \frac{3 \times 22\,200 \times 250^2}{8 \times 18 \times 10^{-6}}\left(1 - \frac{3{\cdot}66}{D_{32}}\right),$$

$$D_{32}^2 - 13{\cdot}4 = 2{\cdot}16 - 28{\cdot}9 + \frac{105{\cdot}6}{D_{32}}.$$

Whence $$D_{32}^3 + 13{\cdot}34D_{32} - 105{\cdot}6 = 0$$
and $$D_{32} = 3{\cdot}8 \text{ feet.}$$

Oblique Sag at 32° F. with $\frac{3}{8}$-inch Ice and 8 lb. wind. —Starting from basic loading conditions—

$$\text{Thermal Expansion} = lK(32 - 22) = 10lK$$

$$\text{Elastic Contraction} = (S_m - S_{32})\frac{l}{M}$$

W is constant $\therefore S_m D_m = S_{32} D_{32}$.

Substituting for S_{32} and putting L for l we have

$$D_{32}^2 - D_m^2 = \frac{30KL^2}{8} - \frac{3S_m L^2}{8M}\left(1 - \frac{D_m}{D_{32}}\right).$$

Inserting known values

$$D_{32}^2 - 4{\cdot}72^2 = \frac{30 \times 9{\cdot}222 \times 10^{-6} \times 250^2}{8} - \frac{3 \times 29\,200 \times 250^2}{8 \times 18 \times 10^{-6}}\left(1 - \frac{4{\cdot}72}{D_{32}}\right),$$

$$D_{32}^2 - 22{\cdot}3 = 2{\cdot}16 - 38 + \frac{179{\cdot}5}{D_{32}}.$$

Whence $$D_{32}^3 + 13{\cdot}54D_{32} - 179{\cdot}5 = 0$$
and $$D_{32} = 4{\cdot}85 \text{ feet.}$$

The maximum *hypothetical* horizontal displacement of the conductor ($4{\cdot}85 \times \frac{\cdot 710}{\cdot 88} = 3{\cdot}92$ feet) occurs with this loading.

Oblique Sag at 62° F. with 15 lb. Wind.—The wind pressure of 8 lb. per square foot corresponds with a wind velocity of 50 miles per hour, which it is considered sufficient to allow simultaneously with an ice loading. It is not the highest value likely to be experienced; in fact, velocities exceeding 100 miles per hour have been recorded and 70 miles per hour is quite common at higher

temperatures. This is of no importance so far as the strength of the wire is concerned but it may cause trouble due to the wires swinging together (see p. 42). We will therefore consider the state of affairs with 15 lb. wind pressure at 62° F.

Let the subscript "w" refer to values for the wind loaded wire and "o" to the wire in still air.

Then $$D_0 = \frac{W_0 L^2}{8T_0} \text{ and } D_w = \frac{W_w L^2}{8T_w},$$

from which $$T_w = T_0 \cdot \frac{W_w D_0}{W_0 D_w} \text{ and } S_w = S_0 \frac{W_w D_0}{W_0 D_w}.$$

Increase of Stress due to wind loading

$$= S_w - S_0 = S_0\left(\frac{W_w D_0}{W_0 D_w} - 1\right).$$

$$\therefore \textit{Elastic Extension} = \frac{S_0 L}{M}\left(\frac{W_w D_0}{W_0 D_w} - 1\right) = \frac{8}{3L}(D_w^2 - D_0^2).$$

From Table I., weight of conductor per foot run $= \cdot 2$ lb. and diameter $= \cdot 317$ inch.

$$\textit{Wind pressure} = \cdot 317 \times \frac{15}{12} = \cdot 396 \text{ lb.}/\text{ft. run}$$

and $$W_w = \sqrt{\cdot 396^2 + \cdot 2^2} = \cdot 443 \text{ lb.}/\text{ft. run.}$$

From Tables II. and III., $D_0 = 2\cdot 765$ feet, and $T_0 = 565$ lb.

$$\therefore S_0 = \frac{565}{\cdot 05} = 11\,300 \text{ lb.}/\text{sq. inch.}$$

Now, substituting known values in equation

$$D_w^2 - D_0^2 = \frac{3 S_0 L^2}{8M}\left(\frac{W_w D_0}{W_0 D_w} - 1\right),$$

we get

$$D_w^2 - 2\cdot 765^2 = \frac{3 \times 11\,300 \times 250^2}{8 \times 18 \times 10^6}\left(\frac{\cdot 443 \times 2\cdot 765}{\cdot 2 \times D_w} - 1\right).$$

Whence $$D_w^3 + 7\cdot 12 D_w - 90 = 0$$

and $$\underline{D_w = 3\cdot 95 \text{ feet.}}$$

The triangle of forces acting on the wire is shown in Fig. 19. Therefore the horizontal displacement of the wire will be

$$3\cdot 95 \times \frac{\cdot 396}{\cdot 443} = \underline{3\cdot 54 \text{ feet.}}$$

The above results are shown diagrammatically in Fig. 20. The angles of deflection for 7/·122 aluminium and 7/·132 steel-cored aluminium, which are electrically equivalent to 3/·147 copper, are shown also for comparison.

The figures shown are for a span length of 190 feet in the case of 7/·122 aluminium and of 310 feet in the case of 7/·132 steel-cored aluminium, these span lengths requiring about the same sag at 122° F. in still air as 3/·147 copper on a 250 feet span.

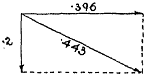


FIG. 19.

(See Chap. X., p. 183, and Tables XVIII. and XIX.)

This figure will be found useful when considering the horizontal spacing to be allowed between conductors (see p. 42).

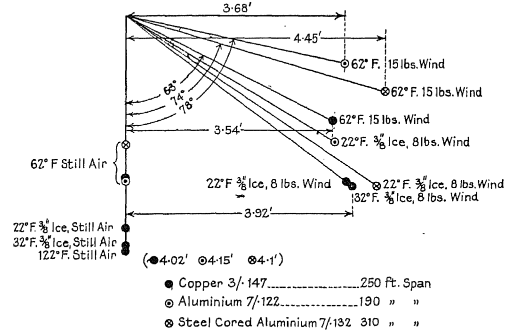


FIG. 20.—Diagram to illustrate movement of conductors under various loading conditions. (H.V. loading.)

Notes on the above Calculations.—No great precision can be claimed for the figures given in the Tables II. to V.

We cannot be certain of the exact values of the modulus of elasticity and of the coefficient of linear expansion, and tolerances of $\pm 1\%$ and $\pm 2\%$ are allowed on the conductor diameter and weight respectively.

But it must be realised that the lineman cannot in practice avoid

errors of a few inches or so when adjusting the sag and the temperature at the time of erection can only be estimated. Even if a thermometer is used, the temperature of the wire in a hot sun may be much greater than the air temperature.

The Tables show the *minimum* sag required by the Regulations, but it is not always necessary or desirable to pull up to the legal limit. There is no point in pulling up to sags less than (say) 1 foot. Frequently in short span work, larger sags are given than are necessary from a legal point of view in order to *reduce* the value of the *terminal stresses*.

Unfortunately, the percentage increase of sag to be allowed on erection in such cases is much greater than the desired percentage decrease in terminal stress under the worst loading conditions. As the Tables cannot therefore be used, the following method of calculating sags and stresses is suggested.

Erection Sags and Tensions with Reduced Basic Loading Stress.—Having decided upon the maximum stress to be allowed, first find the sag at the critical temperature and then the sag at 22° F. without ice and wind.

The sag (and stress) at other temperatures may then be found with sufficient accuracy for practical purposes by assuming a straight line law of variation of sag (and stress) with temperature.

For example, consider a 7/·166 conductor on a low voltage line pulled up to half the maximum tension allowed by the Regulations, *i.e.* 14 250 lb. / sq. in. under basic loading conditions (Table I., p. 4).

(1) **Sag at Critical Temperature.**

$$\theta_c - 22 = \frac{14\,250}{166}\left(1 - \frac{\cdot 595}{\cdot 95}\right).$$

Whence $\theta_c = 54°$ F.

Assume a 200 feet span.

From Table III., page 25, the sag under basic loading conditions ($\frac{3}{16}$-in. ice) with $S_m = 28\,500$ lb. / sq. in. $= 1{\cdot}12$ feet. Therefore the sag under the same loading conditions with half the stress will be increased to $1{\cdot}12 \times 2 = 2{\cdot}24$ feet and this will also be the value of the sag at the critical temperature 54° F.

(2) **Sag at 22° F. without Ice and Wind** (see p. 32).

$$D_m^2 - D_0^2 = \frac{3S_mL^2}{8M}\left(1 - \frac{D_m w_0}{D_0 W_m}\right).$$

Inserting known values, we have .

$$2{\cdot}24^2 - D_0{}^2 = \frac{3 \times 14\,250 \times 200^2}{8 \times 18 \times 10^6}\left(1 - \frac{2{\cdot}24 \times {\cdot}595}{D_0 \times {\cdot}95}\right),$$

$$D_0{}^3 + 6{\cdot}88\ D_0 - 16{\cdot}65 = 0.$$

Whence $\qquad D_0 = 1{\cdot}70$ feet.

We now have

$$\theta = 22°\text{ F.},\ D_0 = 1{\cdot}70\text{ feet},$$

and $\qquad \theta = 58°\text{ F.},\ D_0 = 2{\cdot}24\text{ feet}.$

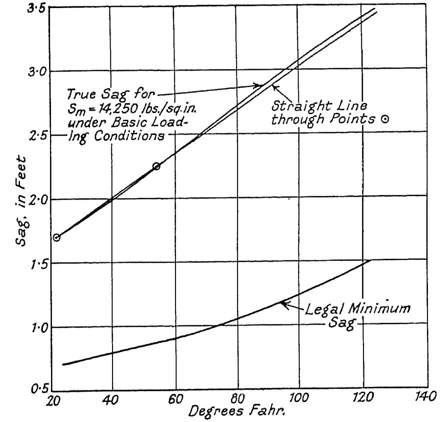


Fig. 21.—Erection sags for 7/·166 copper, 200 ft. span. Low voltage lines.

These points are plotted in Fig. 21 and the straight line drawn through them is seen to be in close agreement with the more exact curve obtained in the manner described on pages 21-23. As a matter of fact, this shorter method of treatment gives fairly good results in most cases, but it is not advisable to use it when working at stresses near the legal maximum.

Solid Versus Stranded Conductors.—For sections above 0·1 sq. in., stranded conductors must be used as solid conductors

become too unwieldy to handle, but between about ·03 and ·075 sq. in. practice differs according to the experience of the engineer. Stranded conductors are undoubtedly easier to handle and less liable to serious damage due to want of skill or carelessness.

For the same cross-section, the stranded conductor is a little more expensive than the solid; the stranded has the larger diameter and therefore a larger wind load, but on the other hand the safe working load of the stranded conductor is higher, and it will be found that the sag to be given to a conductor of given cross-section is sensibly the same whether the conductor is stranded or not. It may be noted that it is not usual to carry the stranding so far with H.D. copper conductors as with the annealed copper conductors used in cables. For example, a standard ·15 sq. in. conductor has 7 strands of ·166 inch diameter in overhead line work and 37 strands of ·072 inch diameter in cable work.

Notes on Sag Adjustment During Erection.—It will be found that when the conductor is erected, the final tension to be allowed is relatively low and may be insufficient to smooth out any slight kinks there may be and to take the initial stretch out of the material.

It is usual, therefore, to pull up the conductor to 60 % of its breaking load (*i.e.* about 20 % greater than the safe working load values given in Column 8, Table I., p. 4) and to maintain this load for a few minutes. It may then be assumed that for practical purposes, the stress will be proportional to the strain over the normal working range—which is, of course, assumed throughout in the above calculations. This applies to both solid and stranded conductors.

If it is impracticable to apply such large loads as the above implies with the larger conductors, then as great a load as possible should be applied and maintained for a couple of days or so.

Having " killed " the wire in this manner, the final sag adjustment can be made as follows :—

(1) *Points of Support at Same Level* (Fig. 22 (*a*)).

Mark off on the supports the distances AM and BN each equal to the appropriate sag from Tables II. or IV. and then adjust the conductor until it just appears in the line of sight between M and N.

If the sag is small it is desirable to check the result with a spring dynamometer, using the figures in Tables III. and V. Another method of checking the sag is referred to on page 42.

(2) *Points of Support at Different Levels* (Fig. 22 (*b*)).

The treatment in this chapter is only strictly correct when the supports are on the same level. When the spans are long and the differences of level large, the design requires special consideration, which is outside the scope of this book, but for short span construction on moderate slopes no difficulties are likely to arise from using the tables of sags and stresses given and proceeding as above.

The length of span must be taken as the horizontal distance between the supports (L) in all cases. On a slope of 1 in 3, however,

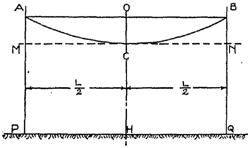


Fig. 22 (*a*).

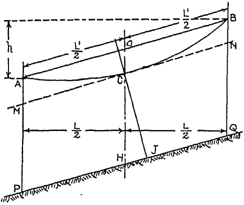


Fig. 22 (*b*).

the length of slope L' (Fig. 22 (*b*)) exceeds L by about 6 % only. It is to be noted also that if the ground surface is parallel to AB and MN, then the vertical distances MP and CH are about 6 % greater than the minimum ground clearance CJ. Therefore, for a given horizontal distance between the supports the poles will have to be somewhat longer on an incline than on level ground.

There may be an upward pull at the lower support A, but in ordinary circumstances this is of no importance when pin insulators are used.

CHAPTER III.

CONDUCTOR ARRANGEMENT, CLEARANCES AND SPACING.

We have to consider—

(1) Clearance of line conductors from ground.

(2) Clearance of earth wire and auxiliary conductors from ground.

(3) Clearance of line conductors from pole and pole ironwork.

(4) Spacing between line conductors. The earth wire may be considered as a line conductor as far as spacing is concerned.

The clearances for (1) and (2) are fixed by the E.C. Regulations (see Appendix I.) and are as follows. The figures are the minimum allowed by the regulations at 122° F., the assumed maximum summer sun temperature in this country:—

(1) Clearance of Line Conductors from Ground.

(*a*) High Voltage Lines.

In all situations at all voltages up to 66 000	20 feet.

(*b*) Low and Medium Voltage Lines.

(i) Public road crossings	19 ,,
(ii) Situations inaccessible to vehicular traffic	15 ,,
(iii) All other positions	17 ,,

(2) Clearance of Earth Wire and Auxiliary Conductors from Ground.

(*a*) High Voltage Lines.

(i) When erected across a public road or canal or across a railway	20 feet.
(ii) Situations inaccessible to vehicular traffic	15 ,,
(iii) All other positions	17 ,,

(*b*) Low and Medium Voltage Lines.

(i) Public road crossings	19 ,,
(ii) Situations inaccessible to vehicular traffic	15 ,,
(iii) All other positions	17 ,,

(3) Clearance of Conductor from Pole and Pole Ironwork.—It will be noted in Fig. 38, page 56, that the dry spark over distance on a typical 11 000 volt insulator is about 5 inches. This may be taken as a rough guide to the working clearance which should be allowed between conductors and metal cross-arms, earthing brackets, etc. The following *minimum* values are suggested :—

Up to	660 volts	4 inches.
,, ,,	6 600 ,,	6 ,,
,, ,,	11 000 ,,	9 ,,
,, ,,	22 000 ,,	10 ,,
,, ,,	33 000 ,,	12 ,,

Bird Trouble.—A good deal of trouble is sometimes experienced due to birds settling on the wires or pole ironwork and causing short circuits or earths, mainly the latter. The result is generally disas-

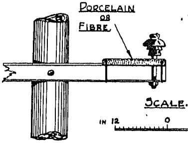


FIG. 23.

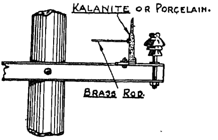


FIG. 24.

trous for the bird but unfortunately its electrocution frequently causes an interruption of supply due to the operation of the leakage protective device. This, of course, only occurs on high voltage systems, and the higher the voltage the greater the nuisance.

To obviate the trouble we may either,

(*a*) ALLOW LARGER CLEARANCES, as for example by using longer insulator pins than would otherwise be necessary.

(*b*) DISCOURAGE BIRDS FROM SETTLING.

The designs shown in Figs. 30, 31 and 32, pages 46-48, appear to be quite satisfactory. Birds are seldom found to settle on the slanting surfaces provided.

(*c*) PROVIDE INSULATED PERCHES OR "BIRD GUARDS."

Two types are illustrated in Figs. 23 and 24. In this connection it is to be noted that bird guards are not necessary with oak arms, if the earth connections to the insulator pins are fixed under the arms.

A rubber-wax compound known as *Pernax*, which is a tough, flexible and durable insulating material of high dielectric strength, obtainable in sheet and tube form from the *Croydon Cable Works*, can also be recommended for wrapping round arms, conductors and stay wires.

(4) **Spacing Between Conductors.**—It will be obvious that the closer the conductors are together the better from a mechanical point of view, since shorter poles and smaller and lighter pole fittings can be used.

Up to (say) 33 000 the working voltage has little bearing on the matter.

The HORIZONTAL SPACING will first be considered. This is decided mainly from the possibility of the conductors blowing together in strong winds. Smaller conductors should, therefore, have relatively larger horizontal spacing, not only because the sags are larger, but also because of the greater ratio of wind loading to weight, which results in a greater displacement from the vertical for a given wind pressure. Table XIV., page 106, illustrates this point.

If a wire hanging freely in a parabolic curve is displaced from the vertical and then released, it will swing regularly, and, considered as a compound pendulum, it can be shown that the relation between the sag in feet (D) and the number of *half* swings per minute (N) is given by the equation $D = \frac{14\ 600}{N^2}$. This relationship is plotted for sags up to 10 feet, in Fig. 25, which will be found useful when checking sags during erection.

If, therefore, all the conductors are erected with precisely the same sag they should swing together synchronously, and there should be nothing to fear from contacts, but unfortunately exact equality of sag is difficult to effect and maintain in practice, and consequently the various conductors may have different periods of swing. Actually, of course, in a gusty wind the movements are very erratic, particularly of the smaller and lighter conductors. From a theoretical point of view, to render it physically impossible for two conductors in the same horizontal plane to touch one another, it would be necessary to allow a spacing equal to twice the maximum horizontal displacement of each conductor due to the highest wind pressure likely to be experienced. This assumes the conductors to swing 180 degrees out of phase, but a little thought will show that such a contingency is very remote, and it is found practically that a spacing about equal

to the maximum horizontal displacement gives a good factoı safety.

Reference to Table XIV. (p. 106) and Fig. 20 (p. 35) will sl that there is some justification for the following practical rules H.V. lines. (Somewhat smaller spacings, say, 20 % less, will usu suffice for L.V. lines, with a minimum of 1 foot) :—

Horizontal Spacing (that is, the distance between conduc when fixed in the same horizontal plane, as in Figs. 26 and 27) :-

Copper.—Allow a spacing equal to sag in still air at 62° F.
Aluminium.— ,, ,, $1\frac{1}{2}$ times ,, ,, ,,
Steel Cored Aluminium.—Allow a spacing equal to $1\frac{1}{4}$ times in still air at 62 F°.

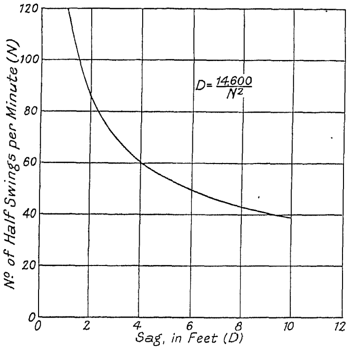


Fig. 25.—Measurement of sags by swings.

Vertical Spacing.—In this case there is no danger of the w swinging together if equally loaded, but we have to consider possibility of an upper conductor becoming more heavily loa than a lower one due to unequal quantities of ice or flocks of b Moreover, a number of birds settling on a lower conductor at s distance from centre of span may cause the conductor to be li up in the other half of the span sufficient to make contact with upper conductor. It is generally inadvisable to fix high vol

conductors above one another *exactly* in the same vertical plane for these reasons (Fig. 28).

Logically, the vertical spacing should bear some relationship to the ratio of ice load to the weight of the wire alone, but the practical rule which is usually worked to is :

VERTICAL SPACING (Copper Conductors).—Allow 1 foot per 100 feet length of span (with a minimum of 1 foot).

This spacing gives a reasonable factor of safety for conductors up to 3/·18 (·075 sq. in.), but is on the generous side for the larger copper conductors.

Perhaps it should be made clear that by "vertical spacing" is meant the vertical distance between horizontal planes through the conductors on the *same side of the pole.*

Somewhat larger vertical spacings should be allowed with the smaller aluminium and steel-cored aluminium conductors.

It is to be remarked, however, that a large number of lines, both in this country and abroad, appear to be giving satisfactory service with spacings much less than these rules demand. On long spans, of the order of 600 to 900 feet, it is observed that the wires *do* swing synchronously, the deflection in strong winds being several times as great as the spacing between conductors. It will be noted in Fig. 25 that the rate of change of N with D falls rapidly with the larger sags, and, further, the small differences in sag inevitable in erection are comparatively insignificant, expressed as percentages. Moreover, comparatively large conductors are generally used on these long spans.

Arrangement of Conductors.

HIGH VOLTAGE LINES.—Figs. 26 to 32 show examples of conductor arrangement on single circuit H.V. distribution lines, with earth wire but without auxiliary conductors for protective gear or telephones. The clearances shown in the figures are suitable for 3/·147 conductor on 250 feet spans. The mechanical strength of the pole fittings will be considered later.

It will be found generally that a horizontal arrangement of conductors allows a shorter pole to be used and this may be of importance in some cases, unless the vertical arrangement is indicated by other considerations.

An equilateral triangular arrangement (Figs. 26, 27 and 32) is best from a purely electrical point of view and is therefore desirable, if nothing is lost thereby; but this is not a ruling factor in

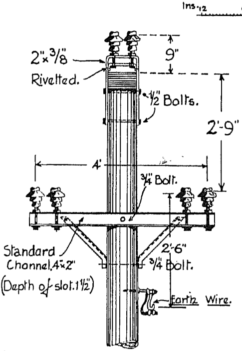


Fig. 26.

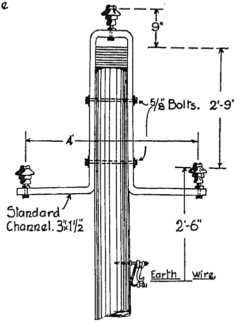


Fig. 27.

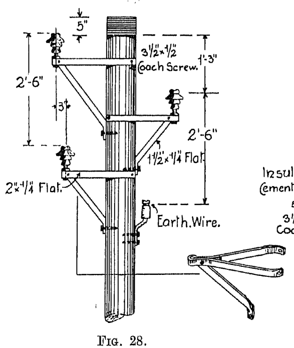


Fig. 28.

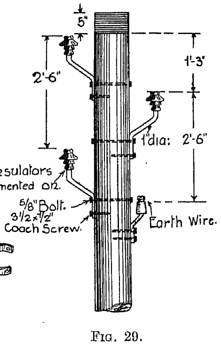


Fig. 29.

Simple types of H.V. pole fittings.

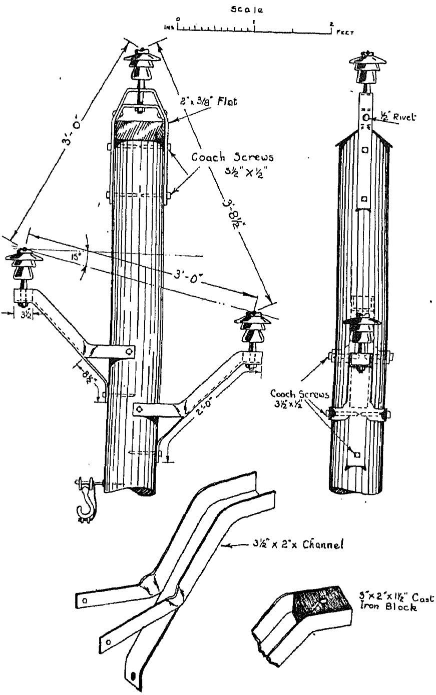


FIG. 30.—Type of H.V. pole fittings.

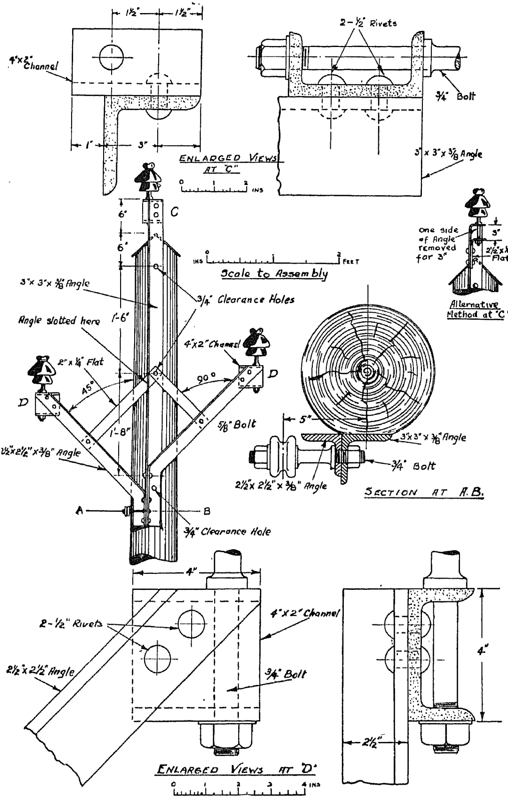


FIG. 31.—Type of H.V. pole fittings.

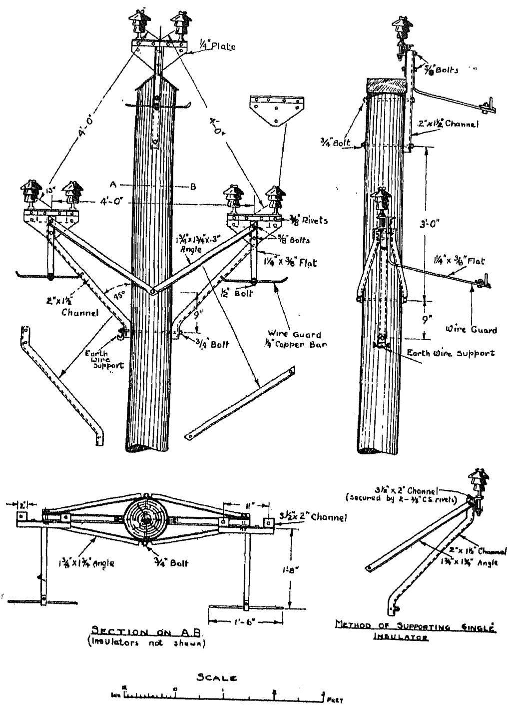


Fig. 32.—Type of H.V. pole fittings. (Callender's standard design.) 3 000-20 000 volts, double insulators and wire guards.

distribution work, and if the nearest standard pole is a little on the short side, the vertical distance between the conductors in these three designs may safely be reduced to 30 inches.

Figs. 30 and 31 are examples of the "tilted" triangular arrangement which is favoured by some engineers, there being no two conductors in the same plane, horizontally or vertically. It can easily be verified by trial that, for the same spacing between conductors, the factor of safety against contacts is greater than with the arrangement of Figs. 26, 27 and 32, in which the two lower conductors are in the same horizontal plane.

Figs. 26 and 32 show double insulators which are specified by the Electricity Commissioners in the neighbourhood of roads.

Although the conductor clearance from the ground must be at least 20 feet in all cases, a clearance of 15 feet only is required for the earth wire across country, and it may, therefore, be two or three feet lower than shown in the figures. Advantage may be taken of this to ease up the load on the pole, but the higher the earth wire is fixed, the more effective it is as regards atmospheric effects.

Low Voltage Lines.—Some examples of L.V. conductor arrangement are given in Figs. 33 to 36.

L.V. distribution is invariably short span work on account of service connection which must be taken off at the poles, and for which reason it is frequently more convenient to arrange the conductors in a vertical plane (Figs. 35 and 36) in spite of the somewhat longer poles thereby necessitated. The use of poles for street lighting also has a bearing on the question of span length. Owing to the relatively short spans and the less onerous hypothetical loading conditions it is not usually necessary or desirable to pull up the conductors to the limit of tension allowed by the regulations, as the increased difficulty and cost of dealing with the stresses at angles and terminals is far greater than any saving which might be effected in the cost of supporting poles.

It is, of course, necessary, mainly for æsthetic reasons, to allow the same sags on all sizes of conductors on the same poles, but in cases where this point arises, the span length seldom exceeds 150 feet.

Fig. 33 shows an arrangement suitable for a 4-wire L.V. feeder (without branches), with a "split" neutral, which was required by the old (1923) E.C. Regulations. The new (1928) Regulations permit a single wire neutral to be used with this design, provided the wire

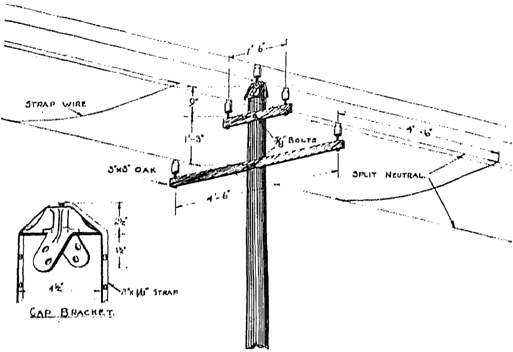


FIG. 33.

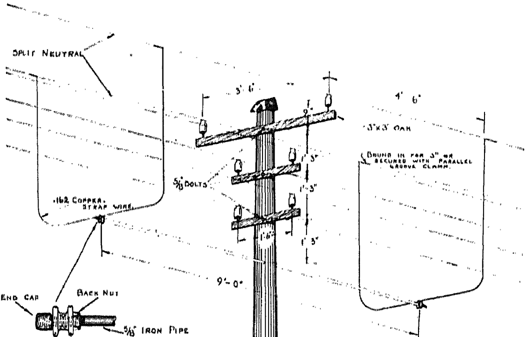


FIG. 34.

Types of L.V. pole fittings.

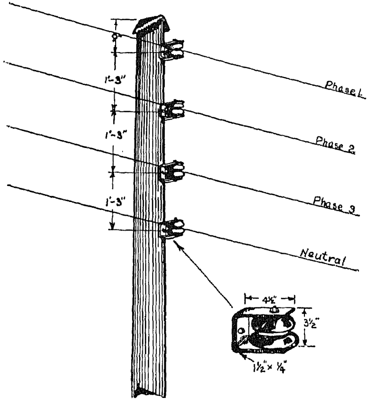


FIG. 35.

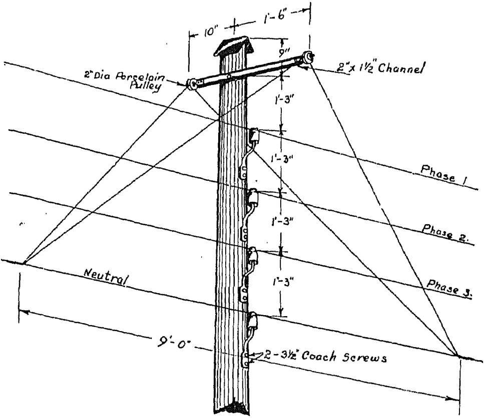


FIG. 36.
Types of L.V. pole fittings.

is staggered from one side of the pole to the other, but this appears to present practical difficulties.

Fig. 34 shows 3-phase wires, 1 switch wire, and a " split " neutral, also erected to comply with the old Regulations.

Fig. 35 shows a vertical arrangement which now complies with the Regulations, the single wire neutral being considered sufficient as a guard wire when it is directly below the phase conductors.

Fig. 36 shows a vertical arrangement with a " V " guard, required by the old Regulations, but now no longer necessary.

As the insulation of the shackle (Fig. 35) is inferior to that of the shed insulator (Fig. 36) it is better to use the latter type as far as possible in straight runs and for small angles, and reserve the former for terminals and considerable angles.

H.V. and L.V. Lines on Same Poles.—The idea of using the same poles for both H.V. and L.V. lines is, of course, by no means new. It has been common practice on the Continent and in America for many years, but has hitherto not been encouraged in this country.

Fig. 37 shows a combined pole which has recently been approved by the Electricity Commissioners and which presents many points of interest.

The Shropshire, Staffordshire and Worcestershire Electric Power Company have gone very carefully into the question of standardisation and the design shown is typical of their standard practice in rural distribution. All drilling and slotting of poles is done before despatch to site. Every pole is slotted to take an 8 in. × 4 in. × 4 ft. foundation block 1 foot 6 inches below ground. This enables a foundation block to be readily fitted if, on excavation, the engineer decides that the nature of the ground is such as to make it necessary. The buried depth of 5 feet 6 inches should be ample for most common types of soil, but the 1928 E.C. Regulations are really more onerous than the old ones concerning pole foundations.

The vertical spacings between conductors is rather less than is recommended elsewhere in this book, but the values allowed have been found to give satisfactory service in the area of supply concerned.

The minimum clearance between H.V. and L.V. lines is 19 inches. The pole brackets will be seen to be of very simple design. Ordinary standard insulator pins are used with distance pieces of iron tube between the strap brackets. One L.V. phase conductor only is shown, but the poles are of sufficient diameter and length to accommodate

3-phase conductors, when required. The L.V. phase conductors are insulated with P.B.J. insulation (see Specification, Appendix IV., p. 231).

The short pieces of straight iron strap marked " a " on the L.V.

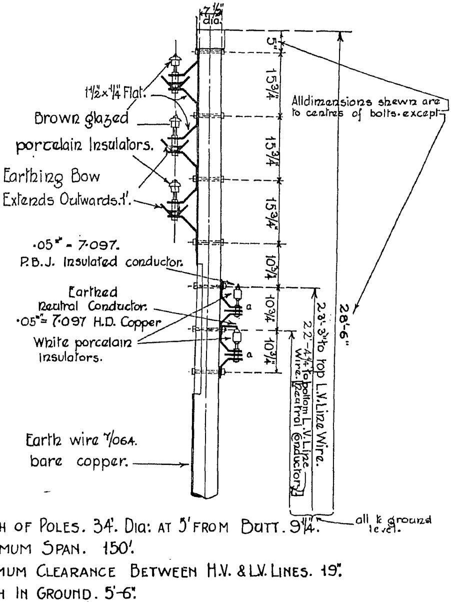


FIG. 37.—H.V. [3 300 volts] and L.V. [230 volts to earth] on same pole [Shropshire, Staffordshire and Worcestershire Electric Power Company].

fittings are drilled so that when turned outwards from the pole they are readily available for service connections by the addition of porcelain pulley insulators.

No continuous overhead earth wire is used, the H.V. ironwork

being connected to an earth plate at every pole. The earth necting wire is covered with creosoted wood casing for a distanc 9 feet from the ground. Earthing bows are fitted on all pole

The L.V. ironwork is connected to the earthed neutral conduc This is sound practice as it puts the ironwork definitely at e potential (or nearly so) and although contrary to the E.C. Reg tions as they stand at present, it has been specially approved in instance.

It may be pointed out that it would be undesirable to com the L.V. and H.V. ironwork to the same earth, as the earth resista may not be low enough to obviate dangerous voltages in the I system in case of insulator breakdowns.

CHAPTER IV.

INSULATORS.

THE material for overhead line insulators must possess a high diele tric strength and insulation resistance, and the insulator should so shaped as to minimise concentrations of dielectric stress due surges which might puncture the material and so render it uns viceable. The shape is, of course, a matter for the designer, and the operating engineer can do is to specify a high ratio of punct voltage to flash-over voltage. A flash-over will probably cause interruption of supply by operating the protective gear, but the sup can be restored immediately without the delay which is inevita if one or more punctured insulators have to be located.

In addition to the electrical properties mentioned above, insulator must, of course, have sufficient mechanical strength support the conductor under all weather conditions.

The material which, in this country, is considered most nea to satisfy all the required conditions is *Porcelain*, the manufact of which has reached a very high standard. The porcelain must absolutely vitreous throughout to render it non-hygroscopic. surface is glazed, not to improve the insulation, but to render diffi the deposit of dirt which increases surface leakage, and to facilit the washing off by rain of whatever dirt does settle. The smo glazed surface also reduces the wear of the conductor by abras The body of the porcelain should be ivory white but the glazing be of any colour, brown being considered the best, as the insula then form less conspicuous targets for small boys.

Porcelain insulators are standardised for H.V. lines (B.S. Sp fication 137—1922).

Pin Insulators, High Voltage.

ELECTRICAL DESIGN.—For voltages up to 33 000, pin type sulators are invariably used.

The various ways in which such an insulator may fail electrically will be clear from Fig. 38 and the table of particulars which follows :

Particulars of Typical Standard 11 000 *Volt Pin Insulator.*

	Inches.	British Standard Test Voltages.
(1) Puncture thickness	·75	108 000
(2) Arcing distance (dry) $A + B + C + D$.	5·0	62 000
(3) Arcing distance (wet) $a + b + c$ . .	2·25	39 000
(4) Leakage distance	7·0	

If the insulator is correctly proportioned with regard to wet and dry arcing distances, the leakage will be negligible.

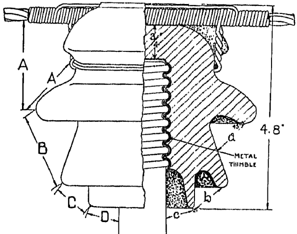


FIG. 38.—11 000 volts porcelain insulator.
Leakage distance = 7 ins.
Dry spark over distance A + B + C + D = 5 ins.
Wet spark over distance $a + b + c = 2\frac{1}{4}$ ins.
Puncture thickness = $\frac{3}{4}$ in.

MECHANICAL DESIGN. — Two strengths are standardised, viz. :—400 lb. and 800 lb. As manufactured, the insulator itself is generally suitable for 800 lb. and the strength is determined by the size of the pin. Reference to Table I. shows that the 400 lb. design is suitable for supporting poles up to a span length of about 400 feet. The 800 lb. insulator comes in for longer spans and also for angles, where the lateral loading includes an appreciable component of the longitudinal tension in the conductors as well as the lateral wind pressure. Pin insulators are not

often used at terminal poles, but they are quite suitable for some of the smaller conductors.

It is important that there should be no appreciable deflection of the insulator pin under load, to avoid possible fracture of the porcelain. The B.S. Specification above referred to lays down a F of S of $2\frac{1}{2}$ *based on the yield point.*

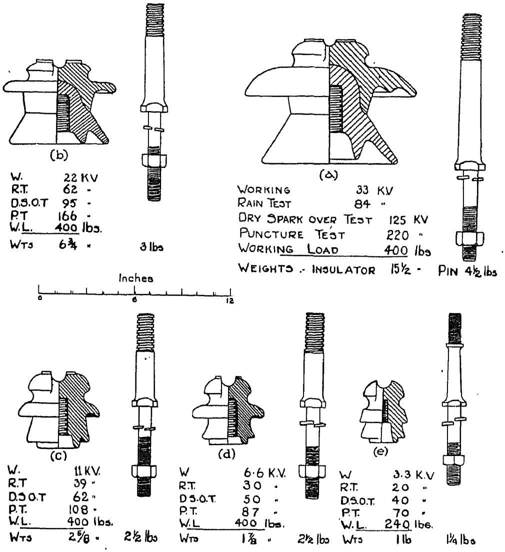


FIG. 39.—Typical high voltage porcelain insulators and pins.

Fig. 39 shows a series of B.E.S.A. Standard high voltage porcelain insulators. It is to be observed, however, that trouble has been experienced with these insulators in very exposed positions, particularly near the sea, and it is the practice of some engineers to use an insulator one grade higher than the British Standard rating.

For example, an 11 000 volt Standard insulator would be used on a 6 600 volt system. It is understood that B.S.S. 137 will shortly be revised.

Loads on Insulators at Angles.—First consider a straight line pole (Fig. 40 (*a*)).

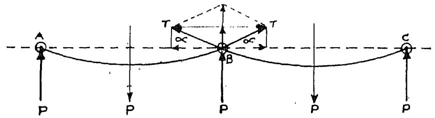


FIG. 40 (*a*).

For simplicity, assume the whole of the load on the conductor to be horizontal and equal to P lb. per span. If the tangent to the conductor at the point of support makes an angle $\propto$ with the direction of the line, the lateral load on the insulator $= P = 2T \sin \propto$ lb., T being the tension in the conductor. The longitudinal forces balance.

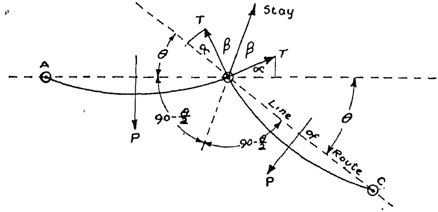


FIG. 40 (*b*).

Now suppose the span BC to swing round through θ degrees (Fig 40 (*b*)), then the resultant horizontal force on the insulator $= P_1$

$$= 2T \cos \beta = 2T \sin \left(\propto + \frac{\theta}{2}\right)$$

$$= 2T \sin \propto \cos \frac{\theta}{2} + 2T \cos \propto \sin \frac{\theta}{2}$$

$$= P \cos \frac{\theta}{2} + 2T \sin \frac{\theta}{2} \cos \propto.$$

In all practical cases the angle α is in a plane inclined to the horizontal, as explained in Chapter II., but the reasoning still holds if it be remembered that T is actually due to the weight of wire + ice loading, as well as to wind pressure.

Now $\tan \alpha = \dfrac{4D}{L}$ and $\dfrac{D}{L}$ is of the order $\dfrac{1}{100}$.

$\therefore \tan \alpha = \cdot 04$ and $\cos \alpha = \cdot 999$. The effect of the angle α on the result is therefore negligible.

If $\theta = 45°$, $\cos \dfrac{\theta}{2} = \cdot 925$, and with the smallest permissible copper conductor on a 200 feet span, $P = 122$ lb. on high voltage lines and $T_m = 633$ lb.

Substituting these values in the above formula we get

$$\text{(i) Neglecting } \cos \frac{\theta}{2},\ P_1 = 606 \text{ lb.}$$

$$\text{(ii) Including } \cos \frac{\theta}{2},\ P_1 = 597 \text{ lb.}$$

The neglect of $\cos \dfrac{\theta}{2}$ therefore introduces an error of $1 \cdot 5$ °/ₒ *on the safe side.*

We may then with sufficient accuracy for practical purposes omit the factors $\cos \dfrac{\theta}{2}$ and $\cos \alpha$ and write:

Resultant Horizontal Load on Insulator

$$= \left(P + 2T_m \sin \frac{\theta}{2}\right) \text{ lb.}$$

Values of $2 \sin \dfrac{\theta}{2}$ are plotted in Fig. 41.

As a matter of fact this formula gives pessimistic values not only because of the omission of the two factors referred to above, but also because the wind cannot blow at right angles to both spans simultaneously.

In our example, using 3/·147 copper conductor on a 250 feet span, $P = \cdot 710 \times 250 = 177 \cdot 5$ lb., and $T_m = 1\,457$ lb. If θ is the maximum deviation permissible, we have

For the 400 *lb. pin.*

$$P_1 = P + 2T_m \sin \frac{\theta}{2},$$

$$400 = 177{\cdot}5 + 2 \,.\, 1457 \sin \frac{\theta}{2},$$

from which $2 \sin \frac{\theta}{2} = {\cdot}153$, and therefore, from Fig. 41, $\theta =$

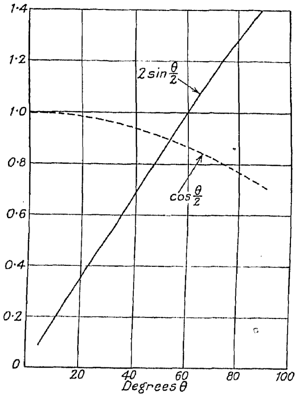


FIG. 41.

For the 800 *lb. pin.*

$$800 = 177{\cdot}5 + 2{\cdot}\, 1457 \sin \frac{\theta}{2},$$

whence $$2 \sin \frac{\theta}{2} = {\cdot}428 \text{ and } \theta = 25°.$$

If the angle pole is double armed and two 400 lb. pin insulator are used, we may assume that they share the load equally, and there fore the same angle (*i.e.* 25°) can be negotiated as with an 800 lb. pin

Table VI. shows the maximum angles which can be dealt wit by the two standard sizes of pin on the span lengths suggested i Table XIV., page 106.

TABLE VI.—*Maximum Angles for Standard H.V. Pin Insulators.*

	Span Length, feet.	Wind Load, H.V. Loading P, lb.	Maximum Longitudinal Tension, T, lb.	400 lb. Pin, degrees.	800 lb. Pin, degrees.
·162 . .	200	122	633	25·0	65·0
·193 . .	250	157	874	16·0	42·0
3/·147 . .	280	199	1 457	8·0	25·0
3/·18 . .	315	239	2 125	4·0	16·0
7/·136 . .	335	258	2 935	2·5	11·0
7/·166 . .	350	291	4 265	1·5	7·0
7/·193 . .	335	297	5 635	1·0	5·0

It will be seen from the above figures that the heavy loads due to the larger conductors make it desirable to avoid small angles and to adhere as far as possible to absolutely straight runs between definitely strengthened angle poles with tensioning insulators.

In practice, however, these standard pins are frequently used for larger angles than those given, although calculations show that tensioning insulators should really be used. Immunity from trouble in such cases is undoubtedly due to the fact that the maximum hypothetical loading conditions are rarely experienced.

In this connection it may be repeated that it is often desirable to allow somewhat larger sags than the E.C. Regulations demand in order to keep down the values of the longitudinal stresses at angles and terminals. This remark applies particularly to L.V. lines in which, relatively, the spans are short and the conductors large.

Methods of Securing Insulator to Pin.—The following methods are commonly employed :—

(1) Pin screwed directly into the porcelain.

(2) Pin screwed into a metal thimble, which is cemented into the insulator.

(3) Insulator cemented on to the pin.

The first two methods are generally to be preferred as they permit the insulators and pins to be transported and handled separately and of insulators being easily replaced. Moreover, the fitting is done in the factory instead of on the job. But in the first method, the hard unyielding joint is likely to lead to cracking of the porcelain under temperature changes, and the sharp edges of the metal thread are undesirable from an electrical point of view. These disadvantages are not serious with small insulators and low voltages and an india-rubber or felt washer on the shoulder of the pin minimises the

effects of unequal expansion of the steel pin and the porcelain a
lessens the risk of fracture when screwing on.

For large insulators at high voltages the second method is
variably used in this country (see Fig. 38, p. 56).

The third method, that of cementing the insulator on to
pin, makes a sound job when well done, and it may have to be
sorted to abroad. Care must be taken to use a cement that will n
act chemically on the pin so as to produce a substance which expa
and breaks the porcelain. Sulphur must on no account be used

Neat Portland Cement (B.S. Specification 12—1920) is the saf
material for the purpose. As the insulators reach a very hi
temperature in the sun it is fortunate that the coefficient of therm
expansion of iron, portland cement and porcelain are not very d
ferent. Iron has a rather larger coefficient than the other two, b
it happens that the cement has the smallest modulus of elastic
and strength under compression which enables it to act as a cush
between the iron and the porcelain.

The cement mixture should be in the ratio of 1 pint of wa
to 4 lb. of cement, in which proportion it has a semi-fluid co
sistency.

Care must be taken to *fix* the pin *centrally* in the hole of the
sulator and to ensure particularly that there is a layer of ceme
between the end of the pin and the bottom of the hole.

The cement takes at least 48 hours to set, but the insulators c
be removed from the framework after 24 hours, if handled careful

Plaster of Paris is sometimes used and appears to give sat
factory service, though not nearly so strong as cement. It has t
advantage of setting more quickly. To prepare the mixture, m
some ordinary carpenter's glue to the consistency usual for wo
joints and dissolve it at the rate of $\frac{1}{20}$ pint of glue to one gall
of water. Then make a plaster of paris mixture with the consisten
of soft putty. Although the setting commences in about 40 minut
the insulator must not be moved for 2 hours, nor placed in positi
on pole for 24 hours.

It is perhaps unnecessary to say that this cementing on shou
not be done in frosty weather.

Methods of Securing Wire to Insulator.—It will
obvious that the side groove must be used at angles. Whether t
top groove or the side groove is used in the straight is a matter
opinion, but the top is most largely used.

It must be remembered that the insulator is standardised for a pull on the side groove, and the bending moment on the pin is somewhat greater when the wire is in the top. Moreover it is impossible to make such a good job of the binding-in when the wire is in the top groove. For heavy conductors the top groove must be used, as the lineman cannot hold the wire in the side groove when making off. It is an advantage for the wire to lie in the side groove on the pole side of the insulator as there is then less chance of the wire falling if the insulator is broken.

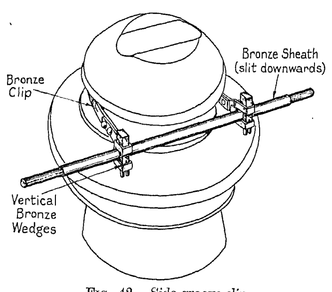


FIG. 42.—Side groove clip.

The ideal binder should be strong enough to prevent the wire from slipping to and fro through it with every change in temperature due to inequality of span lengths, but it should allow the wire to slip before the elastic limit of the pin is reached. It should also be as flexible as possible to prevent the setting up of crystallisation in the conductor.

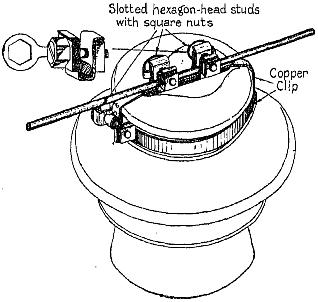


FIG. 43.—Top groove clip.

The use of MECHANICAL CLIPS is sometimes preferred to the usual method of attaching conductors to insulators by means of binding wire. Fig. 42 illustrates a clip for the side groove and Fig. 43 one for

the top. The side groove clip requires a special tool but makes good job and is certainly a time saver. It is made with ho zontal wedges for use when the insulators have flat upper shee The top groove clip which is of soft copper also makes a good jc saves time and the only tool required is a screwdriver. These m chanical clips (especially the top groove design) naturally cost good deal more than binding wire, but on the other hand they requi less skill and time.

The following methods of binding-in and terminating are su gested. Table VII. gives the lengths of binding wire required f the various sizes of conductor. The use of side-cutting pliers shou be forbidden.

Side Groove.—Starting with the middle of the binding wire a point P (Fig. 44 serve the conduc tor for a lengt equal to the dia meter of the nec of the insulator.

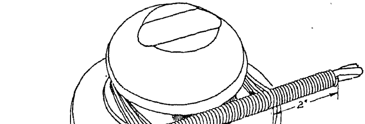


FIG. 44.—Side groove binding.

Take the en which leads of from the top o the line wire (cal this end A), pass it round the neck of the insulator and take a round turn from above downwards, round the conductor.

Then take the other end (B), pass it round the neck of the insulator and take a round turn from below upwards round the conductor.

Finally, pass both ends round the neck of the insulator again and finish off with a serving on the conductor of about 2 inches on each side of the insulator, end A winding from below upwards and end B from above downwards.

If these instructions are carefully followed the turns of wire round the neck of the insulator will not ride one upon another.

Top Groove.—Divide the length of binding wire given in Table VII into two equal parts and lay up together to form a double wire. leaving Z inches of single wire at each end (see Table VII., last column),

Starting with the middle of the double binding wire at point *P* (Fig. 45) serve the conductor for a distance equal to the diameter of neck of insulator plus half an inch (*i.e.* $\frac{1}{4}$ inch at each end).

Twist the double wire together at each end until the bottoms of the twists reach the neck of the insulator and then pass one wire of each pair in a clockwise direction round the neck and the other in a counter clockwise direction.

Twist the pairs together again when they meet until on bending upwards the tops of the twists just reach the conductor.

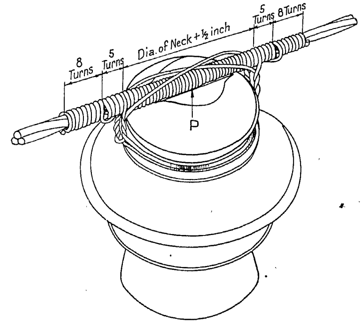


FIG. 45.—Top groove binding.

(These two wires must go round the conductor in the same direction.)

Now take 4 or 5 turns round the conductor with the short wire of each pair.

Finally, take the other wire of each pair, pass them over the top of the insulator so that they cross each other and the conductor, and finish off with 7 or 8 turns round the conductor.

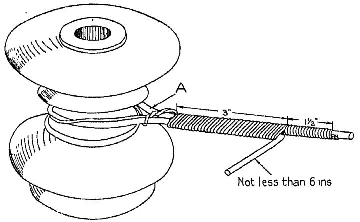


FIG. 46.—Small conductor termination.

Terminating Small Conductors (Fig. 46).—Pass the conductor round the neck of the insulator and lay up the free end along the line part for 3 inches (for wires below ·162 inch diameter, 2 inches will do). The bends in

TABLE VII.—*Lengths of Binding Wire Required for Copper Conductors.*

Size of Conductor.	Diameter of Conductor.	Diameter of Neck of Insulator or Shackle.	Size of Binding Wire, S.W.G.	Length of Binding Wire Required. Termination.	Side.	Top.	Overlap when Laying up Wires for Top Binder. Z.
	Ins.	Ins.		Ft. Ins.	Ft. Ins.	Ft. Ins.	Ins.
.136	·136	3	14	4 0	8 0	7 0	7
·162	·162	3	14	6 0	8 6	7 6	7
·193	·193	3	14	7 0	9 0	8 6	8
3/·147	·317	3	14	9 6	11 0	11 0	10
3/·18	·388	3	12	10 0	11 0	11 0	12
7/·136	·408	3	12	—	11 0	11 0	12
7/·166	·498	3	12	—	12 0	13 0	14
7/·193	·579	3	12	—	13 0	14 0	16

Approximate lengths of 1 lb. of Copper Binding Wire are: 12 S.W.G., 30 feet; 14 S.W.G., 50 feet.

The lengths naturally vary with the size of the insulator, and the exact figure should be determined by trial in particular cases, but the Table will assist when estimating. The table allows for a layer of binding wire on the conductor itself where in the groove, to prevent chafing between the wire and the neck of the insulator. This is considered good practice in this country, and incidentally it helps to prevent burning of the conductor when a "flash-over" occurs. Alternatively copper tape may be used as a chafer, in which case some 20 to 30 % less binding wire will be required.

the conductor at the point *A* must not be too sharp. Then bend out the free end at right angles, leaving sufficient length (not less than 6 inches) for connection to leading-in cable.

Now pass a length of binding wire round the insulator, twist the two ends together and then, with the double binding wire, bind the free end of the conductor to the line part for the 3 inches overlap, finishing off by serving the single conductor for a length of 1½ inches.

Terminating Large Conductors.—The common methods employed are shown in Fig. 47.

H.V. Tensioning Insulators.—Four strengths of tensioning insulators are standardised for H.V. lines, *viz.* 400, 800, 1 200 and 2 400 lb., but they can be obtained for loads up to 10 tons if required in special cases.

Figure 47 illustrates four distinct types which are in use.

Type "a," the SHACKLE Insulator is good mechanically and is quite suitable for L.V. work. It is also used on H.V. work for voltages up to 6 600 volt, but above that it becomes unwieldy in size.

Type "b," the HEWLETT INTERLINKED type has been extensively used in the past and is a good design mechanically.

Type "*c*" is also an Interlinked type similar to type "*b*," but it is claimed that the porcelain is shaped so as to cause a better distribution of the dielectric stress.

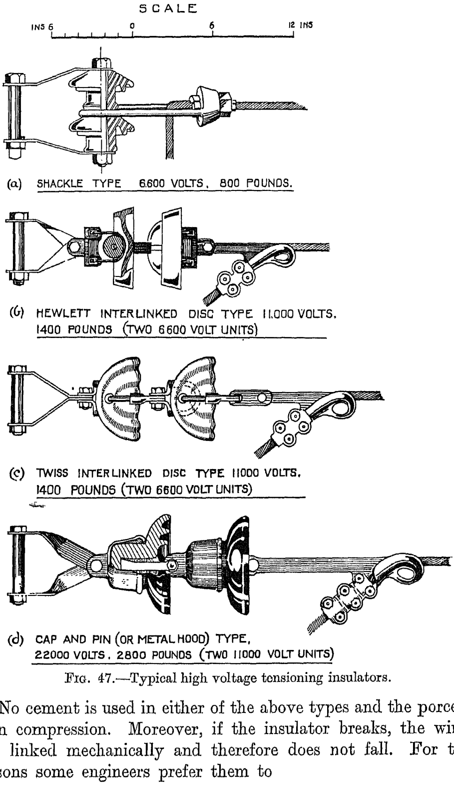


Fig. 47.—Typical high voltage tensioning insulators.

No cement is used in either of the above types and the porcelain is in compression. Moreover, if the insulator breaks, the wire is still linked mechanically and therefore does not fall. For these reasons some engineers prefer them to

Type "d."—This type, which is called the METAL HOODED, or CA AND PIN, TYPE, will be seen to have the porcelain in tension and th cement in shear, and the design is a radical departure from that whicl was rigidly adhered to in the early days, when the porcelain was use in compression only. But the porcelain of to-day is more uniforml reliable than it was in the past, and this design has been used suc cessfully for some years. Recent improvements in the methods o fixing the pin, *e.g.* the "split ring" method, have enabled thi type to be manufactured for working loads up to 8 tons. It i certainly by far the best design for very high voltages owing to th uniform dielectric stress distribution.

However, for the moderate high voltages used in distributio work, the types mentioned may be considered to be equally reliabl and a choice made on the basis of first cost.

Insulators of Materials other than Porcelain.—Ex perience justifies the opinion that British porcelain has no superio as an overhead line insulator and it is now strongly fortified by B.S. Specification.

But GLASS cannot be entirely neglected. It has been and sti is largely used on the Continent, and it is much cheaper than Britis porcelain.

Up to 22 000 volts at least modern continental designs of glas insulator appear to be thoroughly reliable, and it is a pity that th manufacture of glass suitable for H.V. Insulators has not bee seriously undertaken in this country.

But both porcelain and glass are very fragile, and it is probabl true to say that more line breakdowns are due to broken or defectiv insulators than to all other causes put together.

Owing to this drawback, many attempts have been made t produce a satisfactory substitute. Among such substitutes whic have been placed on the market may be mentioned KALANIT (Callenders Cable and Construction Co.), TELENDURON (Thoma De La Rue & Co.) and EBONESTOS (Ebonestos Insulators, Ltd.)

All these materials are tough and non-hygroscopic, and initially at any rate, they have the requisite dielectric strength. They appea to give satisfaction on telegraph and telephone lines and on powe lines up to about 6 000 volts, but they are more expensive tha porcelain.

STEATITE, a naturally occurring magnesium silicate, has electric properties equal to those of porcelain and very much higher tensil and bending strengths.

Insulators of this material can be made absolutely puncture proof. They are reputed to stand up well to stone throwing, but at present their high cost limits their use to special situations.

Another material which shows promise is Fused Basalt, a dark-coloured rock of volcanic origin which can be moulded to almost any desired shape at a temperature of 2 300° F.

It is claimed to have all the advantages of porcelain, and in addition it has a strength of about 18 tons per square inch both in tension and compression, and possesses the remarkable property of resealing itself when punctured. Moreover, it is said to be cheaper than porcelain. It is understood that a number of insulators of this material are on trial in this country.

In the present state of development none of these materials can be recommended to replace porcelain except steatite, but they might be tried in sections of a line subject to trouble from stone throwing.

There is a fortune awaiting the inventor of a material which has all the electrical advantages of porcelain, with its durability but without its fragility.

CHAPTER V.

CROSS ARMS AND INSULATOR BRACKETS.

THE methods of supporting the insulators and securing them to the pole afford much scope for ingenuity.

It is axiomatic that the poles should be cut and drilled as little as possible after creosoting. The sapwood only absorbs the creosote impregnation, and it is therefore important to avoid penetrating the heartwood when cutting slots. All slots, holes, etc., cut in poles should be painted with a hot creosote tar mixture (2 creosote, 1 coal tar).

Table VIII. gives particulars of some useful angle and channel sections.

For pin insulators, the channel section with the web vertical is better than the angle owing to the greater depth for securing the pin, but the angle is much stronger, weight for weight, in the direction of the line, and can be adapted for the fitting of standard insulator pins by inserting an oak block.

Power engineers do not favour the use of timber cross arms, but their prejudice appears to be unjustified when one considers the fifty years' experience of the Post Office with arms of oak and other hardwoods. Wood impregnated with bakelite varnish, known as BAKELISED WOOD, has recently been introduced by a French firm. It is stated to have a tensile strength three times that of the untreated wood and a very high dielectric strength. It appears to be a very promising material to use for cross arms and insulator pins (and possibly for the insulators themselves) in situations near the coast where porcelain insulators give trouble due to the salt-laden air when fitted to steel pins and pole fittings.

All pole ironwork should be galvanised when possible. After immersion for twenty minutes in a solution of hydrochloric acid in water (equal parts acid and water) the parts should be immersed in a bath of pure molten zinc, and then placed at an angle to set.

When ironwork is made up locally galvanising may not always

TABLE VIII.—*Particulars of Steel Sections.*

Material.	Section.	Weight per ft. lb.	Area A sq. in.	Moment of Inertia, J.	Strength Modulus, Z.	Radius of Gyration, k.
CHANNEL.	*2 × 1½	3·84	1·125	0·24	0·25	0·465
	*2 × 1½			0·65	0·65	0·760
	3 × 1½	4·60	1·352	0·261	0·255	0·439
	3 × 1½			1·823	1·215	1·161
	*3½ × 2	6·75	1·986	0·713	0·526	0·599
	*3½ × 2			3·701	2·115	1·370
	4 × 2	7·09	2·085	0·703	0·502	0·581
	4 × 2			5·063	2·532	1·558
	5 × 2½	10·22	3·006	1·641	0·95	0·739
	5 × 2½			11·873	4·749	1·987
	6 × 3	12·41	3·650	2·825	1·339	0·880
	6 × 3			21·271	7·09	2·414
EQUAL ANGLE.	1½ × 1½ × ¼	2·34	·687	·134	·128	·441
	1½ × 1½ × ¼			·056	—	·286
	1¾ × 1¾ × ·3	3·26	·960	·255	·21	·515
	1¾ × 1¾ × ·3			·108	—	·335
	2 × 2 × ·3	3·77	1·110	·392	·28	·594
	2 × 2 × ·3			·164	—	·384
	2½ × 2½ × ·375	5·90	1·735	·962	·55	·745
	2½ × 2½ × ·375			·402	—	·482
	3 × 3 × ·375	7·17	2·110	1·72	·81	·903
	3 × 3 × ·375			·712	—	·581
	4 × 4 × ·425	10·95	3·220	4·752	1·663	1·215
	4 × 4 × ·425			1·953	—	·779

The lesser values of J and k must be used for struts. With the exception of those starred, the above particulars have been extracted by permission of the British Engineering Standards Association from British Standard Specification No. 6 for rolled steel sections for structural purposes. (See p. vii.)

be practicable, in which case the parts should be immersed in bath of hot gas tar (300° F.) thinned with a little gas oil, until t iron attains the temperature of the bath, and then placed at an ang to set. On erection a couple of coats of tar varnish or bitumast solution should be given.

For simple rectangular sections, if $b =$ breadth and d the depth,

$$J = \frac{bd^3}{12} \quad Z = \frac{bd^2}{6} \text{ and } k = \cdot 289d.$$

For circular sections of diameter D,

$$J = \frac{\pi D^4}{64} \quad Z = \frac{\pi D^3}{32} \text{ and } k = \cdot 25D.$$

Eccentric Loading.—For eccentric loading producing com bined bending and direct stress, if T and C represent the direc tensile and compressive loads in lb., M the bending moment i lb.-inches, Z the strength modulus in inch units and A the area c section in sq. ins., then the following formula will give the maximun tensile and compressive stresses in the lb./ sq. inch,

(i) *When* DIRECT STRESS IS TENSILE.

$$f_t = \frac{T}{A} + \frac{M}{Z_t}$$

$$f_c = \frac{M}{Z_c} - \frac{T}{A}.$$

(ii) *When* DIRECT STRESS IS COMPRESSIVE.

$$f_c = \frac{C}{A} + \frac{M}{Z_c}$$

$$f_t = \frac{M}{Z_t} - \frac{C}{A}.$$

In the absence of precise information, the following values for ultimate stresses, etc., of ordinary mild steel, Norwegian red fir and oak may be *assumed in calculations.*

Special steel may be obtained of more than double the strength of ordinary mild steel, and is generally preferred for insulator pins. The figures for timber are good average values.

Table IX.—*Ultimate Strengths of Mild Steel,* Oak, and Red Fir.*

Mild Steel.		
(i) Ultimate Tensile Stress, Tensile	65 000	lb. / sq. in.
(ii) „ „ „ Compressive	55 000	„
(iii) „ „ „ Shear	50 000	„
(iv) Elastic Limit, Tensile or Compressive	36 000	„
(v) „ „ Shear	27 000	„
(vi) Modulus of Rupture (Bending)	60 000	„
(vii) „ „ Elasticity, E	30×10^6	„
English Oak.		
(i) Ultimate Stress, Tensile—		
(*a*) Parallel to grain	10 000	„
(*b*) Perpendicular to grain	900	„
(ii) Ultimate Stress Compressive—		
(*a*) Parallel to grain	8 000	„
(*b*) Perpendicular to grain	2 000	„
(iii) Ultimate Stress, Shear—		
(*a*) Parallel to grain	800	„
(*b*) Perpendicular to grain	4 000	„
(iv) Modulus of Rupture (Bending)	9 000	„
„ „ Elasticity, E	$1{\cdot}2 \times 10^6$	„
Norwegian Red Fir.		
(i) Ultimate Stress, Tensile—		
(*a*) Parallel to grain	8 000	„
(*b*) Perpendicular to grain	500	„
(ii) Ultimate Stress Compressive—		
(*a*) Parallel to grain	6 000	„
(*b*) Perpendicular to grain	1 500	„
(iii) Ultimate Stress Shear—		
(*a*) Parallel to grain	500	„
(*b*) Perpendicular to grain	4 000	„
(iv) Modulus of Rupture (Bending)	7 800	„
(v) „ „ Elasticity, E	$1{\cdot}2 \times 10^6$	„

* Although referred to as "iron" in the colloquial sense in various places throughout the book, "Mild Steel" (·2 % carbon) is the material most commonly used in overhead line work.

Good quality wrought iron, however, is very little inferior in strength to mild steel.

Selections from the many types of pole ironwork met with are shown in Figs. 26 to 37, and to assist the reader to form opinions as to their respective merits and demerits some rough calculations are given.

In practice it may not be usual to calculate very closely, neither is it possible to be very precise, but from an inspection of some types of fitting in use, the writer is of opinion that there is sometimes a lack of appreciation of the stresses to be dealt with and that it is fortunate for the engineer concerned that the hypothetical loading conditions are seldom experienced.

The importance of preventing deformation of the ironwork und stress must be emphasised. Any appreciable movement will alt the stress distribution in the insulator and may lead to fracture the porcelain. The designs are checked on the basis of the maximu (lateral) horizontal and vertical loadings, but there may always l a certain amount of unbalanced longitudinal pull. The latter ma reach large values at angles since, as mentioned before, the wir cannot be at right angles to both spans simultaneously. Moreove reversals of stress occur when the direction of the wind changes ar the fitting of struts, ties and bolts is never perfect.

For the above reasons it is desirable to keep the working stress low. It is proposed to allow a factor of safety of 2·5 on the elast limit of iron and steel in tension, shear and bending and on the crip pling load for struts. For the timber a factor of safety of 3·5 on th ultimate stress will be taken. All struts will be assumed to be hinge at both ends, although this may appear to be pessimistic in some case

In accordance with the above the Working Stresses will be tak as follows :

Working Stresses in Mild Steel.

I. Direct Tension and Bending.—Safe Working Tensile Stres $= f_t = \dfrac{36\,000}{2{\cdot}5} = 14\,400$ lb. / sq. in.

II. Direct Compression (Struts).—In the following $l =$ effec tive length of strut in inches ; $J =$ moment of inertia in inch units $k =$ radius of gyration in inches ; $A =$ area of cross-section i square inches.

(a) *For values of* $\dfrac{l}{k} > 100$.

Euler's formula for a strut hinged at both ends will be used.

Crippling load :
$$B = \frac{\pi^2 . EJ}{l^2}.$$
$$J = Ak^2.$$

∴ Safe Working Compressive Stress

$$f_c = \frac{10 \;.\; 30 \;.\; 10^6 \;.\; Ak^2}{l^2 \;.\; 2{\cdot}5 \;.\; A} = \frac{12 \times 10^7}{\left(\frac{l}{k}\right)^2} \text{ lb. / sq. in.}$$

(b) *For values of* $\dfrac{l}{k}$ *from* 60 *to* 100.

The following empirical straight line formula will be used (see B.S. Spec. No. 6—1924) :—

Crippling Stress $= f_c = \left(46\,000 - 166\,\frac{l}{k}\right)$ lb. / sq. in.

∴ Safe Working Compressive Stress $= \left(18\,400 - 66\,\frac{l}{k}\right)$ lb. / sq. in.

(c) *For values of* $\frac{l}{k} < 60$.

When $\frac{l}{k} = 60{\cdot}7$, the straight line formula gives $f_c = 14\,400$ lb. / sq. in., which is the maximum value allowed in tension.

Now it is contrary to experience to find members stronger in compression than in tension; so for short struts f_c will be limited to 14 400 lb. / sq. in., although the straight line formula will indicate a larger value.

III. Shear.—Safe Working Shear Stress $= \frac{27\,000}{2{\cdot}5} = 10\,800$ lb. / sq. in.

Working Stresses in Bolts.

Table X.—*Particulars of Bolts (Whitworth Threads).*

Overall Diameter, ins.	Total Area, sq. ins.	Diameter at Bottom of Threads, ins.	Area at Bottom of Threads, sq. ins.
·5	·196	·393	·121
·625	·307	·509	·204
·75	·442	·622	·304
·875	·601	·733	·422
1·00	·785	·840	·554

It is recommended that the Factor of Safety for bolts should be 2·5, also based on the elastic limit, since although the elastic deformation of bolts may be negligibly small as far as the shape of the fitting is concerned, there is always an indefinite tensile and torsional stress in the bolts due to tightening up the nut.

The tensile load might easily be 3 000 lb. which means in a $\frac{3}{4}$-inch bolt a tensile stress of $\frac{3\,000}{{\cdot}304} = 9\,900$ lb. / sq. in. at bottom of threads. The stress may be 15-20 % greater than this due to torsion.

The necessity for large washers on bolts through timber will be apparent.

The bearing pressure under washers may be taken as 25 % greater than the greatest permissible compressive stress allowed in the general design, *e.g.* if the tensile load on the bolt is 3 000 lb., the area of washer should be

$$\frac{3\,000}{\frac{1\,500}{3{\cdot}5} \times 1{\cdot}25} = 5{\cdot}6 \text{ sq. ins.}$$

A 3 in. × 2 in. × $\frac{1}{4}$ in. washer will meet the case.

Bolts through poles should always be a driving fit. To ensure this the hole should be drilled with an auger $\frac{1}{16}$ inch only larger than the bolt.

Coach Screws.—Coach screws are found to be very useful in pole line work when used intelligently.

To fix the screw a hole should be bored a sixteenth less than the overall diameter of the threaded portion of the shank, and if an appreciable part of the unthreaded portion of the shank penetrates the pole provision should be made for it by enlarging the hole to the requisite depth.

Driving the screw part of the way with a hammer, as is frequently done, always lessens the holding power.

A number of experiments have been made to test the holding power of coach screws. Allowing a F. of S. of 3·5 to 4 and rounding off the figures the safe holding power when inserted across the grain in Norwegian Red Fir, per inch of penetration of thread may be taken to be :—$\frac{1}{2}$ inch diameter, 300 lb. ; $\frac{5}{8}$ inch, 350 lb. ; $\frac{3}{4}$ inch, 400 lb.

These figures apply to any direction of pull, providing that the coach screw penetrates the pole up to a point not less than $\frac{3}{8}$ inch under the head. That is to say, the thickness of the material secured to the pole must not exceed $\frac{3}{8}$ inch. If it does the holding power is reduced when the pull is non-axial, although there may be the same length of penetration of thread into the pole.

Working Stresses in Norwegian Red Fir.—The elastic limit for timber is approximately 75 % of the ultimate stress, but there is not the same precision about the figure that there is about the elastic limit of steel. It is proposed to base the Factor of Safety on the ultimate stress in all cases.

Bearing Pressure of Round Bolts on Timber at Bolt Holes.

I. Load at Right Angles to Fibres.—In this case the bearing area may be based on the full diameter of bolt (d).

II. LOAD PARALLEL TO FIBRES.—In this case it can be shown that the effective width of bearing surface is only about six-tenths of the diameter (*i.e.* 0·6*d*), *e.g.* with a $\frac{3}{4}$-inch bolt, the safe maximum working load per inch length of bolt

$$In\ case\ I. = \frac{1\ 500 \times \cdot 75}{3 \cdot 5} = 321 \text{ lb.}$$

$$In\ case\ II. = \frac{6\ 000 \times \cdot 75 \times \cdot 6}{3 \cdot 5} = 771 \text{ lb.}$$

It might be noted in passing that in Case II. there is a load at right angles to the fibres equal to about *one-tenth* of the longitudinal load. This transverse load tends to split the pole and has to be taken into account in designing timber joints, but it is not likely to be of importance in connection with pole fittings.

Case III. LOAD INCLINED TO FIBRES.—In this case the simplest procedure is to resolve into two components parallel and at right angles respectively to the fibres.

Continuing with the $\frac{3}{4}$-inch bolt, if the load per inch length $= P$ at an angle of 30° with the fibres, then the component along fibres $= P \cos 30$ and at right angles thereto $= P \sin 30$.

As far as longitudinal strength is concerned P may be $\frac{771}{\cos 30} = \frac{771}{\cdot 866} = 890$ lb., but it is limited to $\frac{321}{\sin 30} = \frac{321}{\cdot 5} = 642$ lb. by the transverse strength.

We will now consider the various fittings illustrated :—

In the following, $W =$ dead weight of wire plus ice; $P_1 = P + T_m \left(2 \sin \frac{\theta}{2}\right) = P + T_m \propto$, in which $P_1 =$ total lateral load on insulator, $P =$ lateral load due to wind pressure, $T_m =$ maximum safe tensile load on conductor, $\theta =$ angle of deviation of line and $\propto = 2 \sin \frac{\theta}{2}$ which is plotted in Fig. 41, page 60.

Table XI. gives values of W and P for the standard lengths of span suggested in Table XIV., page 106, which will be kept in mind throughout, as well as Table VI., page 61, giving the maximum deviations in the line which are permissible, using standard insulator pins.

TABLE XI.—*Values of W, P and T_m for Standard Spans erected to E.C. Regulations for H.V. Lines.*

Conductor.	Standard Span, feet.	W per foot, lb.	P per foot, lb.	W (total), lb.	P (total), lb.	T_m, lb.
·162	200	·331	·608	66	122	633
·193	250	·379	·629	95	157	874
3 / ·147	280	·521	·710	146	199	1 457
3 / ·18	315	·654	·758	206	239	2 125
7 / ·136	335	·762	·771	255	258	2 935
7 / ·166	350	·999	·832	350	291	4 265
7 / ·193	335	1· 244	·885	417	297	5 635

Fig. 26 (page 45).

Cross Arm.—Suppose wind to be blowing from left to right (Fig. 26 (*a*)) and assume bending at section "*aa*" at centre of arm (*i.e.* neglect support given by slot). First consider the two sides independently.

(*a*) *Right Side.* It is a case of eccentric loading

$$f_t = \frac{P_1}{A} + \frac{M}{Z_t}.$$

$A = 2{\cdot}\,085$ sq. ins., $Z_t = 2{\cdot}\,532$ inch units (Table VIII., page 71), $M = 24W + 8P_1$.

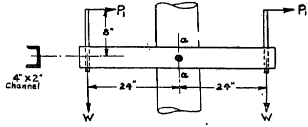


FIG. 26 (*a*).

Maximum value of $P_1 = 800$ lb. when the stronger standard pin is used, therefore for 7 / ·193 conductor on standard 335 feet span

$$f_t = \frac{800}{2{\cdot}\,085} + \frac{24 \times 417 + 8 \times 800}{2{\cdot}\,532}.$$
$$= 380 + 6\,480 = 6\,860 \text{ lb. / sq. in.}$$
$$= \text{stress at outer edge of top flange.}$$

Similarly f_c, the stress at outer edge of bottom flange, $= 6\,480 - 380 = 6\,100$ lb. / sq. in.

(b) *Left Side.*

$$f_c = \frac{P_1}{A} + \frac{M}{Z_c}.$$

$$M = 8P - 24W = 6\,400 - 10\,000 = -3\,600$$

$$\therefore\ f_c = 380 - \frac{3\,600}{2{\cdot}532} = 380 - 1\,420 = -1\,040 \text{ lb. / sq. in.,}$$

i.e. the stress at the outer edge of the top flange is tensile and equal to 1 040 lb. / sq. in. At the outer edge of the bottom flange

$$f_c = 380 + 1\,420 = 1\,800 \text{ lb. / sq. in.}$$

We have, therefore,

Maximum tensile stress in top flange = 6 860 lb. / sq. in.
and maximum compressive stress in bottom flange = 6 100 lb. / sq. in.
These stresses are well below 14 400 lb. / sq. in., the maximum safe working value.

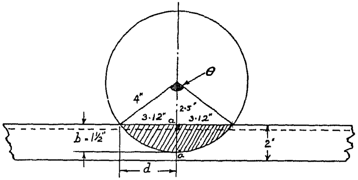


FIG. 26 (b).

The maximum unbalanced tensile stress in the top flange = 6 860 − 1 040 = 5 820 lb. / sq. in. = 5 060 + 760 = $\frac{8 \times 800 \times 2}{2{\cdot}532} + 380 \times 2$, and the unbalanced compressive stress in the bottom flange = 6 100 − 1 800 = 4 300 = 5 060 − 760 = $\frac{8 \times 800 \times 2}{2{\cdot}532} - 380 \times 2$.

The bending moment due to these forces (*viz.* 5 060 × 2·532 = 12 800 lb.-ins.) must be dealt with by the slot.

Strength of Slot (Fig. 26 (b)).—Assume pole diameter $D = 8$ ins. and depth of slot $b = 1\frac{1}{2}$ ins.

$$\text{Area of segment} = \frac{4}{3}bd = \frac{4}{3} \times \frac{3}{2} \times 3{\cdot}12 = 6{\cdot}24 \text{ sq. ins.}$$

Since $b < \frac{D}{2}$ the arc may be assumed to be a parabola for which $J = \frac{4}{15}bd^3$.

$$\therefore Z = \frac{4}{15}bd^3 \times \frac{1}{d} = \frac{4}{15}bd^2 = 3\cdot 90,$$

and
$$k = \sqrt{\frac{J}{A}} = \sqrt{\frac{\frac{4}{15}bd^3}{\frac{4}{3}bd}} = \frac{d}{\sqrt{5}}.$$

Now the maximum compressive stress on the timber in the slot for the values of W and P_1 being considered,

$$= f_c = \frac{C}{A} + \frac{M}{Z_c}$$

$$= \frac{2 \times 417}{6\cdot 24} + \frac{12\,800}{3\cdot 90} = 3\,420 \text{ lb. / sq. in.},$$

but f_c must not exceed 1 715 lb. / sq. in.

$\therefore P_1$ must be reduced from 800

$$\text{to } 800 \times \frac{1\,715 - 134}{3\,420 - 134} = 385 \text{ lb.}$$

Strength of Arm Bolt Fixing (Fig. 26 (*c*)).—The bolt pivots about the centre of the $6\frac{1}{2}$ inch of pole which remains after the $1\frac{1}{2}$-inch slot has been cut.

If f_c is the maximum compressive stress in the timber due to the bending moment on the bolt, we have

$$f_c = \frac{C}{A} + \frac{M}{Z}.$$

Bolt dia. $= 0\cdot 75$ inch; $\therefore A = 6\cdot 5 \times \cdot 75 = 4\cdot 88$ sq. ins.; $C = 2P_1$ lb., and $M = P_1 \times 2 \times (3\cdot 25 + \cdot 12) = 6\cdot 74P_1$.

(If a 3 in. $\times$ 3 in. oak arm were used

$$M = P_1 \times 2 \times (3\cdot 25 + 1\cdot 5) = 9\cdot 5P_1$$

and the method of fixing therefore much weaker.)

The compressive load diagram is shown in Fig. 26 (*c*).

The total load on timber on each side of axis, if f_b = maximum stress due to bending moment, $= 3\cdot 25 \times \cdot 75 \times \frac{f_b}{2} = 1\cdot 217 f_b$.

The centre of pressure of this triangular load

$$= 3{\cdot}25 \times \frac{2}{3} = 2{\cdot}16 \text{ inches from axis.}$$

$\therefore$ Moment of resistance $= 1{\cdot}217 \times 2{\cdot}16 \times 2 \times f_b = 5{\cdot}25 f_b$. Whence $Z = 5{\cdot}25$ inch units.

Substituting known values in the stress equation we have

$$f_c = \frac{2P_1}{4{\cdot}88} + \frac{6{\cdot}74P_1}{5{\cdot}25} = 1{\cdot}7P_1.$$

f_c at right angles to fibres must not exceed $\dfrac{1\,500}{3{\cdot}5} = 429$ lb./sq. in.

$\therefore P_1$ is limited to $\dfrac{429}{1{\cdot}7} = 252$ lb. as far as the timber is concerned.

Now, consider the bolt.

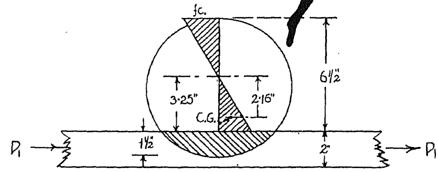


FIG. 26 (c).

The safe moment of resistance of a $\frac{3}{4}$-inch bolt, if we base the F. of S. upon the elastic limit

$$= \frac{\pi d^3 f}{32} = \frac{\pi\,.\,27}{32\,.\,64}\,.\;14\,400 = 597 \text{ lb.-ins.}$$

Assuming no flexure of the bolt, the maximum bending moment on it occurs at the centre and is equal to half the total bending moment,

$$i.e. \quad \frac{6{\cdot}74}{2}P_1 = \frac{6{\cdot}74}{2} \times 252 = 849 \text{ lb.-ins.}$$

As this is too great for the bolt, the total bending moment must be reduced to $597 + 849 = 1\,446$ lb.-ins., and P_1

$$\text{to } \frac{1\,446}{6{\cdot}74} = 215 \text{ lb.}$$

But this is a pessimistic result, since if the nut is tightened up so as to produce a tension of 3 000 lb. in the bolt, the frictional force between the arm and the pole is quite considerable.

Assuming a coefficient of friction of iron on wood of 0·3, this force $= 3\ 000 \times \cdot 3 = 900$ lb., and allowing a Factor of Safety of 3·5 it will enable P_1 to be increased by $\frac{900}{3 \cdot 5 \times 2} \times \frac{3 \cdot 25}{3 \cdot 37} = 124$ lb., making a total of $215 + 124 = 339$ lb.

If, on the other hand, the nut is drawn up lightly we may base the Factor of Safety upon the ultimate strength of the bolt and its moment of resistance would then be $597 \times \frac{24\ 000}{14\ 400} = 995$ lb.-ins. and therefore the timber will give before the bolt.

If the length of the spanner is not too great (12 to 15 times the diameter of the bolt) bolts should always be drawn up as tightly as possible, since the frictional forces help both the timber and the bolt itself and so materially increases the holding power.

It will be seen from the above figures that the simple slot fixing is suitable for all sizes of conductor and span lengths given in Table XIV., *providing the line is quite straight*, but for larger lateral loads such as are experienced at angles, some form of reinforcement is necessary.

We will first consider the effect of adding diagonals as shown dotted in Fig. 26, page 45,

Diagonals.—In order that the diagonals may be effective, it is desirable that there should be no deflection at their points of attachment to the cross arm. The calculations should, therefore, really be based upon deflections rather than upon moments, but it is simpler to consider the latter and the result so obtained is sufficiently accurate for our purpose.

Assuming the dimensions shown in Fig. 26 (d) and taking moments about "a," we have, if C is the compressive load in the right hand diagonal,

$$\frac{C}{\sqrt{2}} \times 16 = W \times 24 + P_1 \times 8.$$

Taking $W = 417$ lb. and $P_1 = 800$ lb., we get $C = 1\ 450$ lb. Similarly for the left-hand diagonal

$$\frac{C}{\sqrt{2}} \times 16 = W \times 24 - P_1 \times 8$$

and $C = 318$ lb.

Now it will be impracticable to use anything less than $1\frac{1}{2} \times 1\frac{1}{2} \times \frac{1}{4}$ angle, owing to the end fixing requirements. For this section $\frac{l}{k} = \frac{17}{\cdot 29} = 58{\cdot}5$. As this is less than 60, the safe working stress $= 14\,400$ lb. / sq. in.

$\therefore$ Max. safe working load $= f \times A = 14\,400 \times \cdot 687 = \underline{9\,900}$ lb.

The section is therefore amply strong enough.

In accordance with the above the load on the slot would be upwards and equal to $1\,025 + 225 - 417 - 417 = 416$ lb., but as explained later, the load on the slot is much more likely to be vertically downwards when the fitting has settled down.

Now consider the strength of the bolts at " *a* " and " *de*." Taking " *de* " first, and assuming that the vertical load on the timber is uniformly distributed, the safe working load $= 1\,715 \times \cdot 6 \times 8 \times$

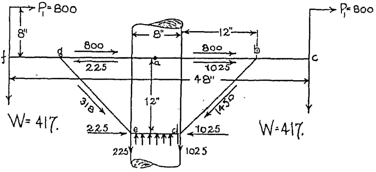


FIG. 26 (*d*).

$\cdot 75 = 3\,080$ lb., so there is ample strength as far as the timber is concerned.

The maximum bending moment on the bolt ($\frac{3}{4}$-inch diameter) $= 1\,025 \times 2{\cdot}125 = 2\,180$ lb.-ins., and its moment of resistance is 1 490 lb.-ins. at the elastic limit.

The frictional force between angle iron and pole may be assumed to increase this by $(3\,000 - 1\,025 - 225) \times \cdot 4 \times 2 \div 2{\cdot}5 = 560$ lb.-ins., making a total moment of resistance of 2 050 lb.-ins. only, which is quite inadequate.

Actually, however, this is a pessimistic result, since although the diagonals should be capable of dealing with the total load initially, flexure of the lower bolt will enable the arm to take its share of the load, and for this reason the maximum bending moment on the bolt should not exceed about one half the value calculated above. Moreover, when the bolt bends, the load distribution on the timber in the

bolt hole is altered, and instead of remaining uniform it becomes greater near the surface of the pole. For a given vertical load, this means a shift of the centre of pressure of the reaction towards the point of application of the load and this reduces the bending moment on the bolt. All things considered, a $\frac{3}{4}$-inch bolt will be found quite suitable for the requirements in this case.

With regard to the bolt at "a," without the diagonals the load on this bolt would be 1 600 lb. With the diagonals, the load is seen to be considerably greater, and it is therefore quite useless to add diagonals, without strengthening the arm fixing, for which the maximum safe load was shown above to be 678 lb. only. The best way to do this is to put a strap round the pole, as shown in Fig. 26 (e). In this way the diagonals will serve a useful purpose for loads up to $P_1 = 800$ lb. on pin insulators. Above this value, tensioning insulators must be used and then P_1 acts along the axis of the arm, thus rendering diagonals really unnecessary, although it might be desirable to retain them. By fixing the arm to the pole by means of a strap in this way the lateral working load at angles is limited only by the buckling strength of the pole.

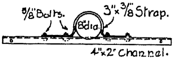


FIG. 26 (e).

Double Arms.—Double arms may sometimes be desirable at angle poles to maintain sufficient clearances between conductor and pole on outside of angle. In this connection, the reader may be reminded that to maintain a spacing of x feet throughout the span, the distance between insulators at angle poles must be increased to $\frac{x}{\sin\frac{\theta}{2}}$, θ being as before the deviation in the line. This is one of the reasons why "H" poles are often used at large angles, another being the limit imposed by the buckling stress of the pole.

Assuming $\frac{3}{4}$-inch bolt and 8-inch pole as before and two $1\frac{1}{2}$-inch slots, the safe working load on the timber in the bolt hole

$$= 5 \times \cdot 75 \times 429 = 1\,610 \text{ lb.}$$

The bending moment on the bolt with this load

$$= \frac{1\,610}{2} \times \left(\frac{5}{4} + \cdot 12\right) = 1\,100 \text{ lb.-ins.}$$

For reasons explained above this may be considered satisfactory for a value of P_1 of about 800 lb.

Cap Fitting (Fig. 26 (f)).—It must be here pointed out that a distance of 9 inches above the pole, as shown in Fig. 26, is rather on the small side. 10 inches is about the minimum practicable figure, using standard 11 000 volt pin insulators.

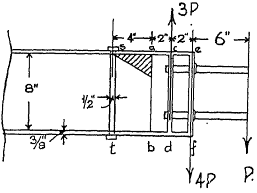


FIG. 26 (f).

To simplify the considerations, assume a theoretical design with the dimensions shown in Fig. 26 (f).

(1) *First consider the part cdfe.* The BENDING MOMENT acting on this part $= 7\,P$ lb.-ins. approx.

The MOMENT OF RESISTANCE to deformation will be four times that of one 2 in. $\times$ $\frac{3}{8}$ in. section

$$= 4\left(\frac{bd^2}{6} \times 36\,000\right) = 4\left(\frac{2 \times 9 \times 36\,000}{6 \times 64}\right) = 4 \times 1\,690$$
$$= 6\,760 \text{ lb.-ins.}$$

To this might reasonably be added the moment of resistance of the two $\frac{5}{8}$-inch insulator bolts

$$= 2\,.\,\frac{\pi d^3}{32}\,.\,36\,000 = \frac{2 \times \pi \times 125 \times 36\,000}{32 \times 512} = 1\,730 \text{ lb.-ins.}$$

$$\therefore P \text{ at elastic limit} = \frac{6760 + 1730}{7} = 1\,210 \text{ lb.}$$

(2) *Now consider the other part abcd.* Between ab and cd the fitting is a girder without a web, and it is, therefore, relatively weak as far as shearing is concerned.

If the connections at c and d were pivoted, the shearing load P acting along the line cd would produce bending moments in the two flanges independently, and they would share the load equally if the lower flange were supported at b. But actually the unsupported length of the lower flange is 6 inches and of the upper 2 inches only and as the deflections are proportional to the cubes of the lengths it will be clear that the upper flange takes most of the load. It is, therefore, suggested that the MOMENT OF RESISTANCE to deformation is the sum of the moments of resistance of the sections at a and c = $2 \times 1\,690$ lb.-ins. The BENDING MOMENT due to the shearing load $= 2P$ lb.-ins. $\therefore P = 1\,690$ lb.

In the practical design the effective lengths of *ac* and *ce* depend upon the fitting of the cross strap, but the above treatment is sufficient to indicate roughly how the strength will be affected by altering the dimensions.

Experimentally, the fitting shown in Fig. 26, with a single rivet on each side was found to have an elastic limit of 1 300 lb. approx. and therefore a maximum safe working load of 520 lb.

The following points may be noted :—

(1) The rectangular shape is necessary in the example chosen in order to take double insulators, but sloping the sides inwards as shown in Fig. 30 makes a better job with single insulators.

(2) The cross strap should always be bent downwards where riveted to main member so as to reduce the effective length of *ac* to a minimum. Two rivets on each side placed diagonally will enable the working load to be increased a little.

(3) Although it will slightly decrease the value of the safe working load, the distance *ce* may with advantage be increased an inch or so in order that insulator pins of the same length may be used on both cap fittings and cross arms.

(4) $\frac{1}{2}$-inch bolts are shown, but $3\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. coach screws will do equally well.

(5) The upper bolt must be at a sufficient distance from top of pole to avoid crushing the timber. This can be checked as explained on page 80. 4 inches is about right, but it is advisable to plane the pole a little so as to get a flat bearing surface 2 inches wide.

Fig. 27 (page 45).

Consider Section "*aa*" (Fig. 27 (*a*)).

$$f_t = \frac{P_1}{A} + \frac{M}{Z_t}$$

$$= \frac{P + T_m \propto}{A} + \frac{18W + 7(P + T_m \propto)}{Z_t}.$$

$A = 1{\cdot}352$ sq. ins., $Z = {\cdot}255$ inch units.

Introducing values for ·193 conductor on 250 feet span we get

$$f_t = \frac{158 + 874 \propto}{1{\cdot}352} + \frac{18 \times 95 + 7(158 + 874 \propto)}{{\cdot}255}$$

$$= 11\,167 + 24\,645 \propto = 14\,400$$

$$\therefore \propto = {\cdot}13 \text{ and } \theta = 7^\circ \text{ (Fig. 41).}$$

This fitting cannot be used for conductors larger than ·193 on the standard spans considered. It is a simple design but makes very poor use of the material.

Fig. 28 (page 45).

We will consider the top left-hand fitting of Fig. 28 which provides sufficient clearance from the pole for a 22 000 volt line.

Dimensions assumed in calculations are given in Fig. 28 (*a*).

The diagonal may be taken to be a strut concentrically loaded, but the horizontal members are subjected to eccentric loading. In this case we will base the calculations on 7 / ·136 conductor in the straight on a span length of 335 feet for which $W = 255$ lb. and $P_1 = 258$ lb. The direct loads, as determined below, are shown in Fig. 28 (*b*).

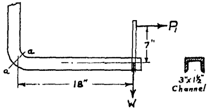


FIG. 27 (*a*).

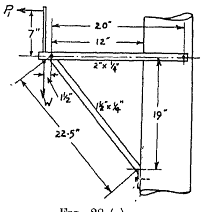


FIG. 28 (*a*).

Load in Diagonal.

If C = Compressive load in diagonal,

$$C \times \frac{19}{22 \cdot 5} \times 20 = 21 \cdot 5W \pm 7P_1.$$

$$\therefore C = 1 \cdot 27W \pm \cdot 415P_1.$$

(i) NO WIND.

$$P_1 = O,\ W = 255,$$

$$\therefore C = 1 \cdot 27 \times 255 = 324 \text{ lb.}$$

(ii) WIND OUTWARDS.

$$C = 1 \cdot 27 \times 255 + \cdot 415 \times 258$$

$$= 324 + 107 = 431 \text{ lb.}$$

(iii) WIND INWARDS.

$$C = 324 - 107 = 217 \text{ lb.}$$

Strength of Diagonal.

$$\frac{l}{k} = \frac{22{\cdot}5}{{\cdot}289 \times {\cdot}25} = 312.$$

$\therefore$ Maximum Safe Working Compressive Load

$$= \frac{12 \times 10^7 \times A}{\left(\frac{l}{k}\right)^2} = \frac{12 \times 10^7 \times 1{\cdot}5 \times {\cdot}25}{312^2} = 462 \text{ lb.}$$

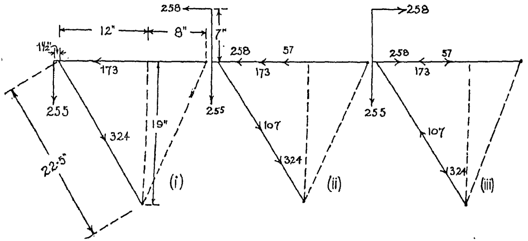


FIG. 28 (b).

Load on Horizontal Members.—The horizontal members make an angle $= \cos^{-1} . 96$ with the direction of P_1. It is proposed to neglect this.

(i) NO WIND.

$$\textit{Direct Load} = C \times \frac{12}{22{\cdot}5} = \frac{12}{19}W = {\cdot}68W = {\cdot}68 \times 255 = 173 \text{ lb.}$$

$$\textit{Bending Moment} = 1{\cdot}5W = 1{\cdot}5 \times 255 = 382{\cdot}5 \text{ lb.-ins.}$$

$$A = 2 \times \frac{1}{4} \times 2 = 1 \text{ sq. in.}; \; Z_t = 2\frac{bd^2}{6} = \frac{2 \times {\cdot}25 \times 2^2}{6} = \frac{1}{3}.$$

$$\therefore f_t = \frac{T}{A} + \frac{M}{Z_t} = \frac{173}{1} + \frac{382{\cdot}5}{\frac{1}{3}} = 1\,320 \text{ lb.} / \text{sq. in.}$$

(ii) Wind Outwards.

$$\textit{Direct Load} = C \times \frac{12}{22{\cdot}5} + P_1 = \frac{12}{22{\cdot}5}(324 + 107) + 258$$

$$= 173 + 57 + 258 = 315 + 173 = 488 \text{ lb. (tensile).}$$

$$\textit{Bending Moment} = 1{\cdot}5W + 7P_1$$

$$= 1{\cdot}5 \times 255 + 7 \times 258 = 2\,200 \text{ lb.-ins.}$$

$$\therefore f_t = \frac{T}{A} + \frac{M}{Z_t}$$

$$= \frac{488}{1} + \frac{2\,200}{\frac{1}{3}} = 7\,088 \text{ lb. / sq. in.}$$

Maximum permissible Tensile Stress = 14 400 lb. / sq. in.

(iii) Wind Inwards.

$$\textit{Direct Load} = 315 - 173 = 142 \text{ lb. (compressive).}$$

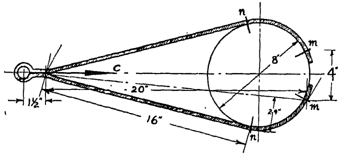


Fig. 28 (c).

Bending Moment.—In this case, the members are curved, and the maximum Bending Moments occur at the points furthest away from the straight lines joining the two ends of the members,

$$\textit{i.e.}\quad M = C \times 2{\cdot}4 \text{ lb.-ins. (Fig. 28 }(c)\text{).}$$

$$\therefore f_c = \frac{C}{A} + \frac{M}{Z_c}$$

$$Z \text{ on weaker axis} = 2\frac{bd^2}{6} = \frac{2 \,.\, 2 \,.\, (\frac{1}{4})^2}{6} = \frac{1}{24}.$$

$$\therefore f_c = \frac{142}{1} + \frac{142 \times 2{\cdot}4}{\frac{1}{24}}$$

$$= 142 + 8\,180 = 8\,322 \text{ lb./sq. in.}$$

(Maximum permissible Compressive Stress = 14 400 lb. / sq. in.)

It may be noted in passing that if additional coach screws were

placed at the points *nn*, where the straps are tangential to the po[le] they would become simple concentrically loaded struts of leng[th] 16 inches and very much stronger to resist wind loading inwar[ds] towards the pole.

It will be seen from the above that the fitting is not suitable f[or] conductors larger than 7/·136 unless the span length is much r[e]duced, and it can only be used with 7/·136 if the line is qui[te] straight. If the calculations are repeated for 3/·18 conductor [it] will be found that an angle of about 6 degrees can be negotiate[d] and of course, with the smaller conductors, much larger angles ca[n] be dealt with.

As it is the relative weakness of the diagonal which is the limitin[g] factor, the fitting can be strengthened at very little cost by increasin[g] the section of this member. The buckling load of a $1\frac{1}{2}$ inch $\times \frac{5}{16}$ inc[h] section is more than double that of the $1\frac{1}{2}$ inch $\times$ $\frac{1}{4}$ inch section use[d].

Actually, the ends of the diagonals are more nearly fixed tha[n] hinged and there is considerable friction between the horizont[al] members and the pole when the diagonal has to support the greate[st] load (*i.e.* when the wind blows outwards). Also, the diagonals ma[y] possibly take some of the direct load P_1, which would tend to reduc[e] the compressive load in it when the wind blows outwards.

These factors are comforting, but should not be made use of i[n] the design.

Strength of Coach Screws.—The coach screw supportin[g] the greatest load is that at the bottom of the diagonal. The vertica[l] component of the maximum load on the diagonal is $431 \times \frac{19}{22 \cdot 5} =$ 365 lb. The length of thread on a $3\frac{1}{2}$-inch coach screw exceed[s] 2 inches and the safe working load is therefore at least $300 \times 2 =$ 600 lb. This neglects the help given by the frictional resistanc[e] between diagonal and pole, so the holding power is ample.

This is a very sensible and cheap fitting and is easy to fix. I[t] may be necessary to fit bird guards in some areas. As stated before the calculations refer to the top left-hand fitting on Fig. 28. Th[e] other two fittings are somewhat stronger.

Fig. 29 (page 45).

Fig. 29 is a weak design, and will only be briefly considered. The maximum safe Moment of Resistance

$$= \frac{\pi \cdot d^3 f}{32 \times 2 \cdot 5} = \frac{\pi \times 1 \times 36\,000}{32 \times 2 \cdot 5} = 1\,415 \text{ lb.-ins.}$$

When the wind is outwards and the conductor in the side groove nearer the pole, the Bending Moment $= 6{\cdot}5W + 13P_1$ [Fig. 29 (*a*)].

Introducing values for the smallest conductor, ·162 on a 200 feet span we get

$$6{\cdot}5 \times 66 + 13 \times 122 = 2\,015 \text{ lb.-ins.}$$

(The shearing and direct compressive loads on the section are negligible compared with the bending load.)

This type is, therefore, ruled out altogether for the span lengths under consideration. It is really an elongated insulator bolt, and its use in H.V. work must be limited to 6 600 volt lines, with small

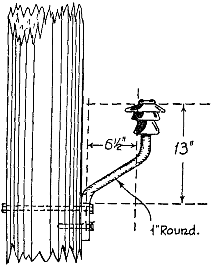


Fig. 29 (*a*).

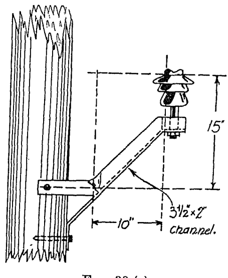


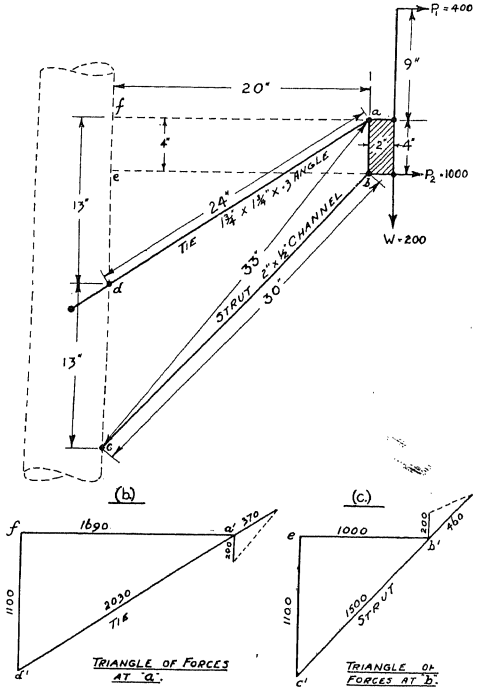
Fig. 30 (*a*).

conductors on short spans. It may be used with ·162 and ·193 copper on span lengths of 130-150 feet in straight runs only.

For L.V. lines, in which the spans are usually short, the hypothetical loading conditions and the required pole clearances are both less, the type will be found useful.

Fig. 30 (page 46).

Side Fitting.—It will be found that the following calculations (similar to those for Fig. 29 (*a*)) determine the strength of this fitting. Providing that the cutting and shaping at the lower end is reasonably well done, the strength of section is increased when opened out.



P_1 = 400
9"
20"
f
a
4"
2"
4"
e
P_2 = 1000
b
13"
24"
$1\frac{3}{4}$" x $1\frac{3}{4}$" x $\frac{3}{16}$ ANGLE
TIE
W = 200
33"
2" x $\frac{1}{2}$" CHANNEL
STRUT
d
30"
13"
c
(b)
(c)
f
1690
a'
370
200
1100
2030
TIE
d'
TRIANGLE OF FORCES AT "a".
e
1000
200
b'
460
1100
1500
STRUT
c'
TRIANGLE OF FORCES AT "b".

FIG. 32 (*a*).

The MOMENT OF RESISTANCE of section at the point where the web is cut away from the flanges

$$= f \,.\, Z = \frac{36\ 000}{2 \cdot 5} \times \cdot 526 = 7\ 580 \text{ lb.-ins.}$$

The BENDING MOMENT on this section $= 10W + 15P_1$ [Fig. 30 (a)].

Introducing values for 7 / ·166 on a 350 feet span, we have in straight runs

$$10 \times 350 + 15 \times 291 = 7\ 865 \text{ lb.-ins.}$$

This is somewhat high, but as we have been conservative as regards working stress, the fitting might be considered about right.

With 3 / ·147 on 280 feet spans, we have

$$10 \times 146 + 15\left(199 + 1\ 457 \times 2 \sin \frac{\theta}{2}\right) = 7\ 580,$$

whence $\theta = 8°$,

that is, the fitting is suitable for an angular deviation in the line of 8 degrees. This is a simple and economical fitting.

Cap Fitting.—This may be checked as explained on page 85. It is stronger than the side fitting.

The calculations for the remaining fittings will be left as exercises for the reader.

Fig. 32 (a) shows the approximate loads on the various members of the Callender side pole fitting illustrated in Fig. 32 (single insulator) with an outward wind load on insulator of 400 lb. and a dead weight load (conductor and ice) of 200 lb.

CHAPTER VI.

SIMPLE WOOD SUPPORTING POLES.

THERE are three types of pole to consider, *viz.* (*a*) SUPPORTS, (*b*) ANGLES, (*c*) TERMINALS. SUPPORTS are poles on which there are normally no longitudinal forces and which have, therefore, merely to support the wires and resist lateral loading due to wind pressure. Unbalanced forces at angles and terminals are dealt with by stays and struts. Single wood poles will be found suitable for most of the lines under consideration and attention will be confined to them in this chapter.

Poles of NORWEGIAN RED FIR are standardised (B.S. Spec. 139—1921) and used very largely in this country. If felled at the correct season of the year and properly seasoned and creosoted they have a useful life of upwards of 40 years. It is specified that the poles shall retain their natural butt.

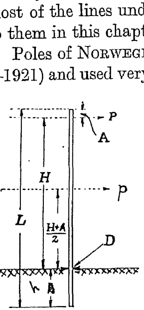


FIG. 48.

The Regulations, however, do not preclude the use of other species of timber, and in this connection the "Cobra" method of impregnation (Cobra Limited, 30 Norfolk Street, Strand, W.C. 2) may be referred to as it can be applied to almost any kind of timber and to standing poles as well as to new poles before erection. The preservative is a water solution of 85 % sodium fluoride and 15 % sodium dinitro-phenate and it is injected by puncturing the pole at various points on its circumference by a special apparatus.

To Determine the Size of Pole Required.

Notation (see Fig. 48).

L = Overall length of pole.

H = Height from ground to point of loading (the point of loading is the centre of pressure due to wind load on all the conductors and wires carried on the pole).

A = Length of pole above point of loading.
h = Length of pole buried in ground.
D = Diameter of pole at ground level.

All the above dimensions in inches.

P = Wind load on wires in pounds.

The BENDING MOMENT on the pole at ground level due to wind load on wires

$$= PH \text{ lb.-ins.}$$

The WIND LOAD ON POLE (neglecting taper)

$$= p = \frac{D(H + A)8}{144} \text{ lb.,}$$

which may be assumed to act at a height of $\frac{H + A}{2}$ inches.

BENDING MOMENT DUE TO WIND LOAD ON POLE

$$= \frac{D \,.\, (H + A)^2 \,.\, 8}{2 \,.\, 144} \text{ lb.-ins.}$$

TOTAL BENDING MOMENT

$$= PH + \frac{D \,.\, (H + A)^2 .\, 8}{2 \,.\, 144}.$$

The MOMENT OF RESISTANCE of a circular section

$$= f \,.\, Z = f \,.\, \frac{\pi D^3}{32} \text{ lb.-ins.}$$

f, the MODULUS OF RUPTURE, has been found experimentally to have an average value of 7 800 lb. per square inch for RED FIR.

Equating BENDING MOMENT to MOMENT OF RESISTANCE and allowing a Factor of Safety of 3·5 as required by the E.C. Regulations we have

$$\frac{\pi D^3}{32} \cdot \frac{7\,800}{3{\cdot}5} = PH + \frac{D \,.\, (H + A)^2 8}{2 \cdot 144}.$$

Whence $$P = 219\frac{D^3}{H} - \frac{1}{36} \cdot \frac{D}{H} \cdot (H + A)^2.$$

All dimensions in inches.

Prepared from this formula, Fig. 49 gives values for the maximum permissible loading for poles from 6 to 14 inches in diameter and of

lengths from 28 to 45 feet, assuming $A = 2$ feet. When P and H are known, the *theoretically* correct size of pole can be determined from this figure and the nearest *standard* size then selected from Table XII.

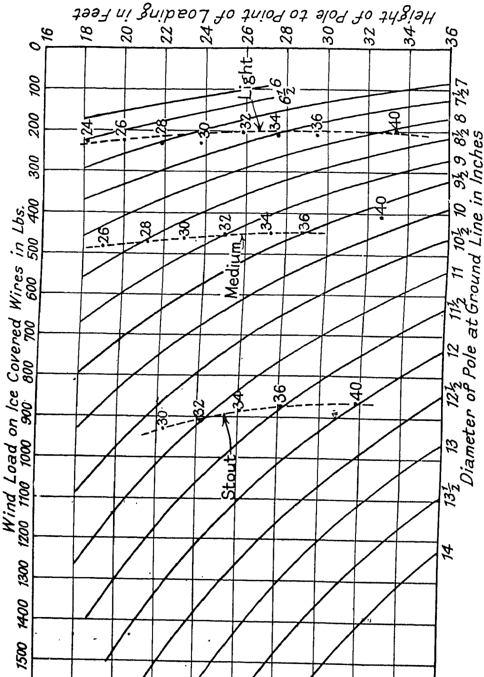


FIG. 49.—Net safe working loads, single wood poles.

TABLE XII.—*Sizes and Weights of Standard Creosoted Fir Poles.*

Light.					Medium.					Stout.				
Length, feet.	Diameter at Top. Minimum, ins.	Diameter at Top. Maximum, ins.	Minimum Diameter at 5 feet from Butt End, ins.	Approximate Weight, cwts.	Length, feet.	Diameter at Top. Minimum, ins.	Diameter at Top. Maximum, ins.	Minimum, Diameter at 5 feet from Butt End, ins.	Approximate Weight, cwts.	Length, feet.	Diameter at Top. Minimum, ins.	Diameter at Top. Maximum, ins.	Minimum Diameter at 5 feet from Butt End, ins.	Approximate Weight, cwts.
18	5	5¾	6	1·5	18	—	—	—	—	18	—	—	—	—
20	5	5¾	6	1·75	20	—	—	—	—	20	—	—	—	—
22	5	5¾	6¼	2·0	22	—	—	—	—	22	—	—	—	—
24	5	5¾	6½	2·5	24	5½	6¾	8	3·25	24	—	—	—	—
26	5	6	6¾	2·75	26	5¾	7	8¼	3·75	26	—	—	—	—
28	5	6	7	3·3	28	5¾	7	8½	4·0	28	—	—	—	—
30	5	6	7¼	3·50	30	6	7¼	8¾	4·75	30	7½	9½	10¾	7·0
32	5	6¼	7¼	4·0	32	6	7¼	9	5·50	32	7½	9¾	11	8·0
34	5	6¼	7½	4·75	34	6	7½	9¼	6·0	34	7½	9¾	11¼	9·0
36	5	6½	7¾	5·25	36	6	7½	9½	7·0	36	7½	9¾	11½	10·5
40	5	6½	8	6·0	40	6	7½	9¾	8·0	40	7½	9¾	12	12·0
45	5¼	6¾	8¾	7·0	45	6½	8	10¾	10·0	45	7¾	10	13	14·5
50	5¼	7	9½	8·75	50	6½	8¼	11½	12·0	50	7¾	10¼	13¾	17·0
55	—	—	—	—	55	7	8¾	12½	14·5	55	8	10½	14¾	19·50
60	—	—	—	—	60	7	8¾	13¼	17·0	60	8	10½	15½	22·75
65	—	—	—	—	65	7	9	14	20·5	65	8	10½	16¼	26·75
70	—	—	—	—	70	—	—	—	—	70	8	10½	17	31·0
75	—	—	—	—	75	—	—	—	—	75	8	10½	17¾	35·5
80	—	—	—	—	80	—	—	—	—	80	8	10½	18¾	40·0
85	—	—	—	—	85	—	—	—	—	85	8	10½	20	45·5

With the exception of the weights, the above particulars have been extracted by permission of the British Engineering Standards Association from B.S.S. 139 for Red Fir wood poles. (See page vii.)

It will be noted that the wind pressure on the pole arms, brackets and insulators is neglected. This is always relatively small and is largely compensated for by assuming the pole to be of uniform diameter, whereas it actually has a taper of about 1 in 100. The assumption that the pole would break at the ground level is close enough for practical purposes. This is where decay sets in, although it may not be theoretically the weakest section in a new pole. The standard poles are rated on their minimum diameter at a point 5 feet from the butt. The section considered above is at a distance from the butt equal to about one-sixth of the overall length, *i.e.* for the lengths most commonly used, distances from 4·5 to 6·5 feet. As the taper is only 1 in 100, no appreciable error is introduced.

"*A*," the length of pole above the equivalent point of loading (*i.e.* the centre of pressure of the wind loads on all the wires) is frequently greater than the 2 feet assumed. The error introduced by this difference is small for span lengths up to 350 feet or so with the most common arrangements of conductors.

Example.—The wind pressure on a single 3 / ·147 (·05 sq. in.) ice-covered conductor ($\frac{3}{8}$ in. ice) = 0·710 lb. per foot run. With four such conductors on a 250 feet span, the total horizontal lateral load on the pole due to wind pressure on the wires = $0·71 \times 250 \times 4 = 710$ lb. This assumes that the diameter of the earth wire is equal to that of the conductors, which is near enough for practical purposes.

Note in Table I. that the wind loading does not vary more than 45 % over the whole range of conductors given. In this case, if a $\frac{7}{16}$ galvanised steel earth wire were used, the wind load would be 157 lb. only instead of 177·5 assumed in these calculations.

The sag at 122° F. = 4·02 feet (Fig. 15, p. 30), therefore (assuming that the point of loading coincides with the point of attachment of the lowest conductor) the required height of pole to point of loading = 20 + 4 = 24 feet approximately.

From Fig. 49, p. 96, we find that for a load of 710 lb., at a height of 24 feet, the diameter of pole at ground level must not be less than 10·2 inches.

If the arrangement shown in Fig. 26, page 45, is adopted, one conductor will be 9 inches above the pole top and the other two conductors 33 inches below, and the total height of the pole out of the ground should be 20 + 4 + 2·75 = 26·75 feet. With 5·5 feet

buried in the ground (see Fig. 55, page 110) the OVERALL LE
POLE required = 26·75 + 5·5 = 32·25 feet.

From Table XII., page 97, it will be seen that the
standard pole which really meets the requirements is 34 f
inches, but a 32 feet / 11 inch pole can be utilised if (which
practicable) the two lower conductors are raised 3 inches.
course, leaves no margin for contingencies, but it is quite
if 250 feet is the *maximum* length of span. If 250 feet is th
length some longer poles will clearly be necessary. In a
when ordering it is advisable to obtain a proportion of the
lengths next above (and a few below) that upon which th
tions are based to allow for variations in length of span and
ground. It may be noted in this connection that the safe
load of standard poles in the same series is approximately
and independent of the length up to about 40 feet.

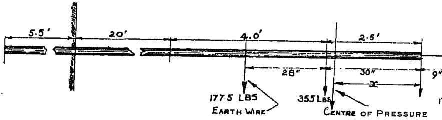


FIG. 50.

This will be clear from the points plotted in Fig. 49, which
the loading point 2 feet from the top of pole and the buried
as shown in Fig. 55, page 110. Therefore, having decided
suitable length of pole for level ground it will not usually be
sary to repeat the calculations for longer or shorter poles wh
no doubt be required in some parts of the line (unless, of cou
loading per foot run is increased in any way such as, for ex
at double-wired road crossings).

The use of standard sizes of wood pole is presumed thro
this book, but it may often be possible to obtain non-standar
at economical prices.

Using 32 feet / 11 inch poles the distances of the various
from the ground will be as shown in Fig. 50.

Check. The total BENDING MOMENT on pole at the groun
will be :—

Cap Wire	$[(26{\cdot}5 \times 12) + 9] \times 177{\cdot}5$	$= 58\,000$
Arm Wires	$24 \times 12 \times 355$	$= 102\,200$
Earth Wire	$(24 \times 12) - 28 \times 177{\cdot}5$	$= 46\,200$
Pole Itself	$26{\cdot}5 \times \frac{10}{12} \times 8 \times 13{\cdot}25 \times 12$	$= 28\,100$
	Total B.M. in inch units	$234\,500$

Therefore Minimum Diameter of Pole required at ground line for a Factor of Safety of 3·5

$$= \sqrt[3]{\frac{234\,500 \times 32 \times 3{\cdot}5}{\pi \times 7\,800}} = 10{\cdot}2 \text{ inches.}$$

The 32 feet pole selected has a diameter of 11 inches at a point 5 feet from the butt. The ground line is 5·5 feet from the butt, therefore the diameter at ground line equals $11 - \frac{{\cdot}5 \times 12}{100} = 10{\cdot}94$ inches approximately and the pole is therefore of ample strength. We will assume in our calculations, however, that the diameter is 10·2 inches only.

Centre of Pressure due to Wind Load on Wires.—Let $x =$ distance of centre of pressure from pole top (Fig. 50), then we have

$$177{\cdot}5(x + 9) = 355(30 - x) + 177{\cdot}5(30 + 28 - x)$$

Whence $$x = 27{\cdot}25 \text{ inches.}$$

Therefore the true height of pole to point of loading (*i.e.* the centre of pressure)

$$= 26{\cdot}5 - \frac{27{\cdot}25}{12} = 24{\cdot}23 \text{ feet,}$$

instead of 24 feet as assumed. This means that a diameter slightly larger than 10·2 inches is necessary, but the difference is negligible.

Use of Chart to Determine the most Economical Span.—The stress in a conductor is inversely proportional to the sag and if the proper sag is allowed, conductors of any size may be erected on practically any length of span with equal safety.

From a purely electrical point of view the longer the span the better, since there are then fewer insulators, which are the weakest points in an installation. The modern tendency is to use long spans, resulting in a reduction in the number of supports and in simplifying the question of wayleaves. But it must not be forgotten that the

individual size, weight and cost of the supports themselves and of the insulators, arms, and brackets increases rapidly with span length because :—

(1) The sag is approximately proportional to the square of the span length.

(2) The wind load is proportional to the span length.

It will be clear, therefore, that there is always a particular span length for which the product "*Cost per Support* × *Number of Supports*" is a minimum.

If a chart is prepared showing—

(*a*) Sag of wires at 122° F. in first quadrant,

(*b*) Wind load on wires in second quadrant,

(*c*) Safe nett loading of poles in third quadrant,

it becomes a simple matter to select the span length which gives *theoretically* the minimum overall cost of the supports.

Fig. 51 has been prepared for this purpose for single circuit high voltage lines with earth wire but without auxiliary conductors, up to 400 feet span.

A similar chart will sometimes be found useful for L.V. lines. For general use it is better to enlarge the chart considerably, and for greater accuracy the second quadrant can be left blank until the particular arrangement and number of conductors to be used is known.

If compound poles are used Figs. 65, 66 and 67 on pages 132 and 133 are available for use in the third quadrant.

To illustrate the use of the chart Table XIII. has been prepared for the 3/·147 (·05 sq. in.) H.V. distribution line in our example.

Where so many factors are involved it was necessary to make a number of simplifying assumptions, among which were : (1) Arrangement of conductors and earth wire as in Fig. 28 ; (2) vertical clearance between conductors on same side of pole, 1 foot for each 100 feet length of span ; (3) centre of wind loading on conductors at point of attachment of lowest conductor.

In preparing the Table, values were tabulated for span lengths varying from 150 to 400 feet at 10 feet intervals, but the only span lengths selected for consideration are those which best fit the standard sizes of poles. The cost figures given are naturally only approximate and are for the supports only erected in fairly good weather. They may have to be increased by 20-30 % in average English winter weather.

TABLE XIII.—*H.V. Line 3 / ·147 Copper Conductors. Single Wood Poles. Support Costs for Various Span Lengths.* [*Conductor arrangement shown in Fig. 28, page 45.*]

Length of Span.	Sag at 122° F. (from chart).	Ground Clearance.	Height of Pole to Point of Loading.	Diameter of Pole at Ground Level (from chart).	Distance of Point of At- [illegible]	Total Height of Pole out of the Ground.	Overall Length of Pole.	Nearest Standard.	Price (including Distribution on Site).	Pole Ironwork, Insulators Dressing and Erection.	Total Cost per Pole.	No. of Poles per Mile.	Total Cost per Mile for Poles.	Capitalised Value of Wayleaves at 5 °/o	Cost of Wayleaves per Mile	Total Cost per Mile of Straight Line (Supports only).
									£	£	£					
150	1·19	20	21·19	8·25	1·9	23·09	27·79	28 / 8½	2·15	1·6	3·75	35·2	123·2	1·5	52·8	176·0
175	1·78	20	21·78	8·75	2·15	23·93	28·83	30 / 8¾	2·50	1·6	4·1	30·2	123·8	1·5	45·3	169·1
195	2·20	20	22·2	9·10	2·35	24·55	29·60	30 / 10¾	3·3	1·6	4·9	27·1	133	1·5	40·6	173·6
240	3·70	20	23·7	10·0	2·80	26·30	31·7	32 / 11	3·7	1·7	5·4	22	119	1·5	33·0	152·0
280	5·20	20	25·2	10·75	3·20	28·40	34·1	34 / 11¼	4·1	1·8	5·9	18·9	110	1·5	28·35	138·35
310	6·50	20	26·5	11·25	3·50	30·0	35·85	36 / 11½	4·4	2·0	6·4	17·0	108·7	1·5	25·50	134·20
350	8·5	20	28·5	11·95	3·9	32·4	38·50	40 / 12	5·2	2·0	7·2	15·1	108·7	1·5	22·65	131·35
400	11·30	20	31·30	12·95	4·4	35·7	42·15	45 / 13	6·4	2·35	8·75	13·2	115·6	1·5	19·80	135·40

An average of 1s. 6d. per annum per pole is taken for wayleaves. A very usual charge for single poles is 2s. 6d. per pole on arable land and 1s. per pole on pasture. All other line costs, including con-

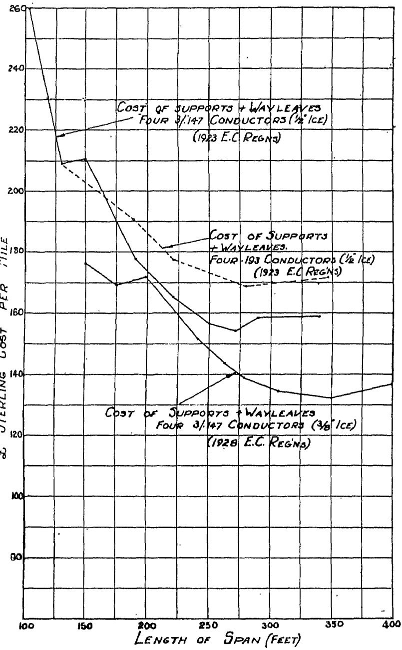


FIG. 52.—Cost of supports for high voltage overhead line. H.D. copper conductors [·05 sq. in.]. Single wood poles.

ductors, stays, reinforcements at crossings, transport, supervision, etc., are assumed to be independent of length of span. Bird guards are not allowed for.

The cost per mile is plotted against length of span in Fig. 5 from which it will be seen that the minimum cost per mile occu with a span of 350 feet, but the variation in cost from 280 to 4(feet is only about 5 %.

This result must be used with discretion. Assuming £131 f(supports and £150 for conductors and earth wire it might be su] posed at first sight that the line could be constructed for £300 or s per mile. But a stretch of several miles of simple straight line : seldom practicable in this country and the reinforcements required a angles, terminals and crossings add appreciably to the overall cos of the line. The contract price for the line under consideratio] would probably be about £500, to allow for overhead charges an(profit, and therefore our saving of 5 % on the cost of the support is reduced to less than 2 % of the overall cost of the line. It i comforting to know, however, that *unless we go to extremes the lengt of the span has little effect upon the overall economy.*

The cost of the supports under the 1923 E.C. Regulations ($\frac{1}{2}$ in ice) is also plotted in the figure and it will be seen that for the con ditions assumed the reduction of the hypothetical ice loading tc $\frac{3}{8}$ inch has effected a saving of about 15 %.

In order to draw attention to a point which is sometimes missed, the costs of supports for ·193 conductors is also shown. It will be noticed that the supports for the smaller conductor are the more expensive. The reason is that, whereas the wind pressure on 3 / ·147 is only 10 % greater than on ·193, the latter has to be allowed 50 % more sag than the former. The difference in this case is only £12 per mile, but in some cases it is larger and it may well be the deciding factor when in doubt as to the advisability of installing a conductor somewhat larger than absolutely necessary from purely electrical considerations.

Further Notes on Selection of Span Length.—It will be noted in Table I., page 4, that on H.V. lines, the wind loading on the largest conductor (7 / ·193) is only about $1\frac{1}{2}$ times that on the smallest (·162), but that the sag required with the smallest conductor is 4 times that required with the largest. Therefore, the larger the conductor, the shorter the pole required for a given span length and the longer the span possible for a given sag.

As a method of making a *tentative* choice of span length up to 350 feet, or so using standard single wood poles, it is *suggested* that the length of span might be based on a sag of about 4 feet in still

air at 62° F. for all sizes of conductor. This may not give the theoretically most economical span, but all things considered, the values so determined give good results.

Table XIV., page 106, is given to illustrate the principles involved. In preparing the table, the span lengths to give 4 feet sag at 62° F. were first selected from Fig. 17 and then altered slightly where necessary so as to make the best use of the nearest size of standard pole.

It will be noted that in some cases it is the length of pole which is the limiting factor and in others it is the butt diameter. In the former cases it will often be practicable to *add a few feet* by means of ironwork so as to increase the conductor clearance from ground, and in the latter it may be economical to use a pole longer than necessary to get the requisite butt diameter and to *cut off a few feet* from the top.

Foundations of Single Poles.—It is laid down in the Electricity Commissioners' Overhead Line Regulations that the supports must be able to withstand the specified maximum hypothetical loading conditions *without movement in the ground.* This requirement is reasonable with most forms of compound wood or iron structures, since any appreciable movement may so alter the distribution of stresses as to seriously weaken the structures. But in certain circumstances a little movement may be most desirable in the case of simple wood or tubular iron poles, particularly if failure of the pole itself is thereby avoided. Moreover, the maximum ground reaction does not become effective until the soil packs up a little due to a small movement of the pole.

Now, the properties of metals are well known, and we can predict with reasonable accuracy the behaviour of good timber under stress, but when we have to deal with soil we can only guess within wide limits.

With regard to the foundations of simple poles it is established that the pole tends to pivot about some point O (Fig. 53 (a)) below ground level, but the exact location of this point is somewhat uncertain.

If the pole is assumed to be absolutely rigid the horizontal displacement (d) at any point will be proportional to its distance from this fulcrum O [shown exaggerated in Fig. 53 (a)].

If it be further assumed that the soil has a definite *elastic modulus*, which is *inversely* proportional to the *depth*, it can be shown that the

TABLE XIV.—*H.V. Lines. Copper Conductors. Suggested Span Lengths.*

Size of Conductor.	Cross-section.	Span Length.	Sag at 122° F. in Still Air (Fig. 15, p. 30).	Height to Point of Loading.	Pole Diameter at Ground Line (see chart, Fig. 51, p. 101).	Depth in Ground (Fig. 55, p. 110).	Height above Point of Attachment of Lowest Conductor.	Overall Length of Pole Required.	Nearest Standard Size of Pole (Table XII., p. 97).	Wind Load on each Conductor (15 lb. Wind).	Dead Weight of each Conductor.	$\frac{\text{Wind load}}{\text{Weight}}$ (15 lb. Wind).	Angle of Deflection (15 lb. Wind).	Sine of Angle of Deflection (15 lb. Wind).	Oblique Sag at 62° F. with 15 lb. Wind.	Horizontal Displacement 62° F. (15 lb. Wind).	Vertical Sag 62° F. in Still Air.	Half Swings per Minute at 62° F. (Fig. 25, p. 43).
	Sq. ins.	Feet.	Feet.	Feet.	Ins.	Feet.	Feet.	Feet.		Lb.	Lb.				Feet.	Feet.	Feet.	
/ ·162	·0201	200	4·62	24·62	9·9	5·0	2·4	32·02	32 / 9	40·4	15·9	2·54	69	·931	4·60	4·29	3·72	62·5
/ ·193	·02926	250	5·80	25·80	10·05	5·4	2·9	34·10	34 / 11¼	60·2	28·1	2·14	65	·906	5·64	5·10	4·63	56·0
3/·147	·05	280	5·20	25·20	10·75	5·65	3·2	34·10	34 / 11¼	111·0	56·0	1·98	63	·891	5·06	4·51	3·80	62·0
3/·18	·075	315	5·40	25·40	11·30	5·90	3·55	34·85	36 / 11½	153	94·0	1·63	58	·848	5·25	4·46	4·00	60·5
7/·136	·10	335	4·85	24·85	11·50	5·95	3·75	34·55	36 / 11½	171	133	1·28	52	·788	4·50	3·55	3·40	65·5
7/·166	·15	350	4·83	24·83	12·00	6·10	3·90	34·68	40 / 12	218	208	1·04	46	·723	4·27	3·09	3·40	65·5
7/·166	·15	410	6·60	26·60	12·95	6·45	4·50	37·55	45 / 13	255	244	1·04	46	·723	5·95	4·30	4·90	54·5
7/·193	·20	335	4·25	24·25	11·95	6·10	3·75	34·10	40 / 12	242	370	0·90	42	·669	3·57	2·39	2·90	71·0
7/·193	·20	400	5·92	25·92	12·95	6·45	4·40	36·77	45 / 13	289	322	0·90	42	·669	5·15	3·44	4·32	58·0

ground reaction stress diagram is *parabolic* in form, as shown in Fig. 53 (*b*), the fulcrum being $\frac{2h}{3}$ from ground level and the moment of resistance of the ground,

$$M_G = \frac{f_b \,.\, D \,.\, h^2}{12} = \frac{k \,.\, D \,.\, h^3}{12} \text{ lb.-ins.}$$

D is the mean diameter of pole below ground level *in inches*, h the depth *in feet*, f_b the maximum rupture intensity of stress of the soil in *lb. per square foot*, k the maximum rupture intensity in *lb. per square foot per foot of depth*, and M_G the MOMENT OF RESISTANCE of ground in *lb. ins.*

If, on the other hand, we neglect elasticity (which requires a

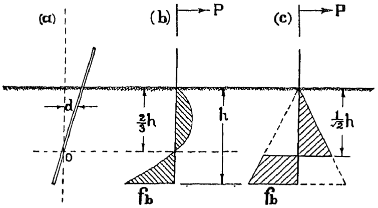


FIG. 53.

stretch of the imagination when dealing with soil) and assume a *maximum rupture intensity* of stress, which is *directly* proportional to the *depth*, then the stress diagram is of straight line form, as shown in Fig. 53 (*c*), the fulcrum $\frac{2}{\sqrt{h}}$ below ground and the MOMENT OF RESISTANCE of ground,

$$M_G = \frac{f_b \,.\, D \,.\, h^2}{10} = \frac{k \,.\, D \,.\, h^3}{10} \text{ lb.-ins.}$$

It will be noted that for a given value of k, the value of h required by the parabolic formula is only about 6 % greater than by the straight line formula, and so for practical purposes the difference is not very serious. It is generally thought that the parabolic formula is more correct in the initial stages of the loading, but when the

foundations are on the point of giving way, the straight line formula is probably more accurate, and it is therefore proposed to make use of the latter formula in this book. The following experiment illustrates its application.

A picket 5 feet long, 3 inches in diameter, 3 feet in ground (loam) began to give at 1 570 lb. pull at ground level at right angles (Fig. 54).

$$\therefore k = \frac{10 M_G}{D \, . \, h^3} = \frac{10 \times 1\,570 \times \frac{3}{\sqrt{2}} \times 12}{3 \times 3^3} = 4930.$$

A similar calculation gives a value of $k = 5\,920$ by the parabolic formula.

In this case the picket was driven in, and the conditions were rather more favourable than in the case of a pole fixed in a hole by

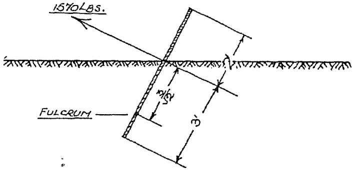


FIG. 54.

means of the earth thrown up in its excavation. If, however, the ramming of the refilled earth is well done k should eventually rise again to the value it had in the virgin soil.

It will be appreciated that precise values cannot be given to k for all the many different kinds of soil. Values up to 8 000 have been obtained in good gravel soil, but for made ground it may be less than 2 000. A conservative value for average good soil is 4 000. With regard to a *Factor of Safety*, the 1923 E.C. Regulations specified 2·5 for the foundations but did not suggest any figures for maximum rupture intensity of the soil. The 1928 Regulations are more vague on this point, but in the explanatory memorandum issued with the Regulations it is implied that the *foundations must be as strong as the pole*. It is proposed in this book to assume values for the maximum rupture intensity of the soil and to allow a Factor of

Safety of 2·5 based on the specified weather loading and not on the strength of the support itself.

It is believed that the foundation calculations in this and subsequent chapters will give sufficiently high factors of safety to satisfy the Commissioners.

Buried Depth Required. Single Wood Poles.—The SAFE MOMENT OF RESISTANCE due to *ground* reaction, neglecting the small difference between the diameter at ground level and the mean diameter below ground, and allowing a Factor of Safety of 2·5,

$$M_G = \frac{k \times D \times h^3}{10 \times 2{\cdot}5} = {\cdot}04k \, . \, D \, . \, h^3 \text{ lb.-ins.}$$

D being the pole diameter at ground level in inches, h the depth in feet and k the maximum rupture intensity in lb. per square foot per foot of depth.

The SAFE MOMENT OF RESISTANCE of the *pole at ground level*, allowing a Factor of Safety of 3·5,

$$M_P = \frac{\pi \times 7\,800}{32 \times 3{\cdot}5} \times D^3 = 219D^3 \text{ lb.-ins.}$$

But the BENDING MOMENT referred to the fulcrum $\frac{h}{\sqrt{2}}$ feet below ground level will be found to be some 10 to 20 % greater than this value. Assuming the bending moment to be 15 % greater and equating one to the other, we get

$${\cdot}04k \, . \, D \, . \, h^3 = 1{\cdot}15 \times 219D^3,$$

$$\therefore \; h^3 = \frac{6\,300D^2}{k}.$$

If $k = 4\,000$ lb. / sq. foot, $h^3 = 1{\cdot}57D^2$.

For pole diameters from 7 inches to 13 inches the formula $h = 0{\cdot}4D + 1{\cdot}4$ is quite near enough for practical purposes.

Curves connecting h and D are given in Fig. 55 for values of $k = 4\,000$ and $2\,000$.

From the lower curve we find that the pole selected in our example should be buried 5·5 feet, and we will now check this value. The BENDING MOMENT on the pole at maximum working load referred to a fulcrum $\frac{66}{\sqrt{2}} = 46{\cdot}5$ inches below ground level

$$= 234\,500 + 46{\cdot}5(177{\cdot}5 + 355 + 177{\cdot}5 + 176{\cdot}5)$$
$$= 234\,500 + 41\,200 = \underline{275\,700 \text{ lb.-ins.}}$$

Now the Moment of Resistance of Ground when the pole is buried 5·5 feet, assuming $k = 4\,000$ lb. / sq. foot

$$= \frac{k \,.\, D_m h^3}{10} = \frac{4\,000 \times 10{\cdot}39 \times 66^3}{10 \times 12^3} = 691\,500 \text{ lb.-ins.}$$

∴ Factor of Safety against overturning

$$= \frac{691\,500}{275\,700} = 2{\cdot}51.$$

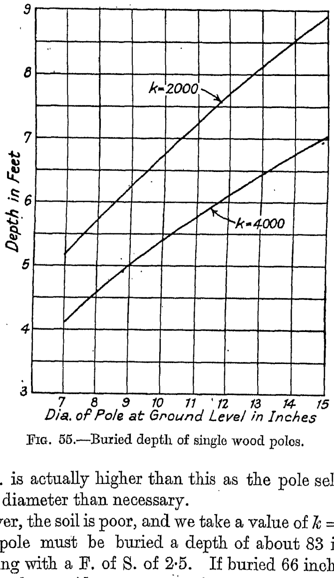


Fig. 55.—Buried depth of single wood poles.

The F. of S. is actually higher than this as the pole selected has a much larger diameter than necessary.

If, however, the soil is poor, and we take a value of $k = 2\,000$ lb. / sq. ft., the pole must be buried a depth of about 83 inches to be self-supporting with a F. of S. of 2·5. If buried 66 inches only, the ground can only provide a moment of resistance of

$$\frac{691\,500}{2} = 345\,750 \text{ lb.-ins.}$$

and therefore a moment of resistance of 275 700 × 2·5 — 345 750 = 343 500 lb.-ins. must be provided by some form of foundation reinforcement.

Assuming cross blocks of creosoted timber are used, one should be placed at a distance of one-third the depth and the other at the full depth, as shown in Fig. 56, as these positions are most effective in the initial stages of the movement.

Let the blocks be 8 inches wide and the areas A_1 (lower) and A_2

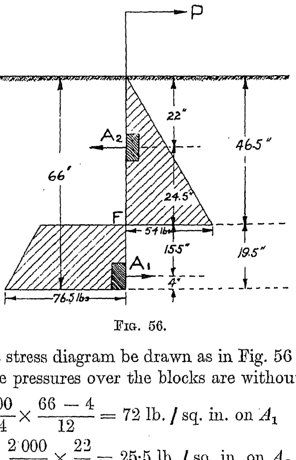


Fig. 56.

upper). If the stress diagram be drawn as in Fig. 56 it will be seen that the average pressures over the blocks are without serious error

$$\frac{2\,000}{144} \times \frac{66 - 4}{12} = 72 \text{ lb.} / \text{sq. in. on } A_1$$

nd

$$\frac{2\,000}{144} \times \frac{22}{12} = 25{\cdot}5 \text{ lb.} / \text{sq. in. on } A_2.$$

If each block provides half the required reinforcement then we ave, taking moments about F,

$$72 \times 15{\cdot}5 \times A_1 = 25{\cdot}5 \times 24{\cdot}5 \times A_2 = \frac{343\,500}{2}.$$

Whence $A_1 = 154$ and $A_2 = 275$ sq. ins.

lowing for area of pole covered by blocks, the total areas should be

Suitable lengths would therefore be 2 feet 6 inches for A_1 and 4 feet for A_2, but conforming with the usual practice A_2 might be made 5 feet, *i.e.* twice as long as A_1. A thickness of 4 inches would be ample. (As a compromise, the pole may be buried about 76 inches and the lower foundation block dispensed with. The amount of excavation required will then be less.)

Size of Bolts for Cross Blocks.—The loads taken by the blocks are approximately as follows (Fig. 56).

$$A_2\ (\textit{Upper})\ \frac{171\ 750}{24{\cdot}5} = 7\ 000\ \text{lb.}$$

$$A_1\ (\textit{Lower})\ \frac{171\ 750}{15{\cdot}5} = 11\ 100\ \text{lb.}$$

Taking f_t for wrought iron as 65 000 lb. / sq. in., assuming 3 000 lb. initial tension in bolt due to tightening up, and allowing a F. of S. of 2·5, we have for

$$\textit{Upper Block Bolt}\quad d = \sqrt{\frac{10\ 000 \times 4}{\pi\ .\ 65\ 000}} = {\cdot}44\ \text{in.}$$

$$\textit{Lower Block Bolt}\quad d = \sqrt{\frac{14\ 100 \times 4}{\pi\ .\ 65\ 000}} = {\cdot}52\ \text{in.}$$

d being the diameter at bottom of threads, it will be advisable to use $\frac{3}{4}$-inch bolts in both cases. Two large washers should be used with each of these bolts.

Shear Stress in Pole above Ground.—It will be found that the shear stress above ground level is quite negligible.

Below Ground.—Load on Upper Block = 7 000 lb.

Load represented by shaded area above the fulcrum F in Fig. 56

$$= \frac{54}{2} \times 46{\cdot}5 \times 10{\cdot}22 = 12\ 800\ \text{lb.}$$

But these figures provide for a F. of S. of 2·5 in the foundation. Therefore the maximum Shearing Force at F at maximum working load

$$= \frac{7\ 000 + 12\ 800}{2{\cdot}5} = 7\ 920\ \text{lb.}$$

the mean intensity. The diameter of the pole at F will be 10·46 inch approximately, therefore,

$$\textit{Maximum Intensity of Shear Stress} = \frac{7\,920 \times 4 \times 4}{\pi \times 10{\cdot}46^2 \times 3}$$

$$= 123 \text{ lb.} / \text{sq. in.}$$

Now the ultimate intensity of shear stress for red fir is about 4 000 lb. / sq. in. across the grain and 500-600 lb. / sq. in. along the grain. There is, therefore, nothing to fear across the grain, but since the intensity of shear stress is equal on planes at right angles there is a F. of S. of about 4 only along the grain at the point F. However, the shear stress falls away from 123 lb. / sq. in. at F to 15·0 lb. / sq. in. at the ground line.

Normally, the shear stress is not a limiting factor with single poles but it is interesting to note that when single poles are tested to destruction the fracture frequently shows signs of longitudinal failure due to shear.

Shearing forces become of great importance in compound poles of the "Rutter" type (p. 116).

Deflection of Single Poles.—It can be shown that, for loads less than the elastic limit, the deflection of a cantilever of uniform cross-section at the point of loading =

$$\delta = \frac{P \,.\, H^3}{3EJ} \text{ inches.}$$

P = load in pounds, H the length to point of loading in inches, E the modulus of elasticity in lb. / sq. in. and J the moment of inertia. Unfortunately E is not very accurately known for timber but from experiments on fir poles it appears to have an average value of about $1{\cdot}2 \times 10^6$ lb. / sq. in.

J for a circular section, about a diameter

$$= \frac{\pi D^4}{64}, \text{ and } P \text{ for a F. of S. of } 3{\cdot}5 = 219 \,.\, \frac{D^3}{H},$$

$$\therefore \delta = \frac{P \,.\, H^3}{3 \,.\, E \,.\, J} = \frac{219 \times 64}{3 \times 1{\cdot}2 \times 10^6 \times \pi} \times \frac{D^3 H^3}{H \,.\, D^4},$$

$$= {\cdot}00124 \times \frac{H^2}{D} \text{ inches.}$$

In our example, $H =$ about 24·23 feet and $D = 10{\cdot}0$ inches, therefore the deflection at the point of loading at the maximum working load

$$= \delta = {\cdot}00124 \times \frac{24{\cdot}3^2 \times 12^2}{10} = 10{\cdot}5 \text{ inches.}$$

This is an elastic deflection, and the pole recovers when the loading is removed.

In the above the taper of the pole is neglected as is also wind pressure on the pole itself, but owing to uncertainty as to the value of E it is useless to pursue the matter further.

It is important to realise, however, that the poles are flexible, and that the flexibility is an advantage. The lateral deflection introduces a component of the longitudinal tension in the wires to help the pole laterally, and the longitudinal deflection which occurs when one or more wires break results in a reduction in longitudinal tension in the sound span and so tends to save the pole from breaking.

CHAPTER VII.

COMPOUND WOOD POLES.

UNFORTUNATELY, for ordinary heights and loads, large portions of trees have to be wasted. To reduce the waste to a minimum, standard poles should be used, but it will generally be found uneconomical to use single poles for lateral loadings much exceeding 1 000 pounds. For ordinary H.V. lines carrying 4 wires this means a limit of span length of about 350 feet, but near the border line there will be cases where it is financially sound to stick to single poles, sacrificing a portion of the top in order to get a larger butt. If auxiliary conductors are installed it will invariably be necessary to use compound poles.

There appears to be a general impression that the overall cost of a transmission line is less if compound poles are used. This was probably true in many cases before the revision of the E.C. Regulations in 1923, but it is certainly not true to-day, at any rate for single circuit 3-phase lines. Compound poles require a good deal more excavation work than single poles, and with the exception of the "Rutter" type they take up a good deal more ground space. The only justification for compound poles in distribution work is the reduction in the *number* of wayleaves required. This minimises negotiation troubles, but there is no financial saving, since the rental for compound poles is about double that for single poles.

Twin Poles.—Consider two poles bolted together side by side, as in Fig. 57.

$$J_{vv_1} \text{ for each pole} = J_{aa_1} + AS^2 = \frac{\pi d^4}{64} + \left(\frac{\pi d^2}{4} \times \frac{d^2}{4}\right) = \frac{5\pi d^4}{64}.$$

$$\therefore Z_{vv_1} \text{ for each pole} = \frac{5\pi d^4}{64} \times \frac{1}{d} = \frac{5\pi d^3}{64}$$

and $$Z_{yy_1} \text{ for the twin pole} = \frac{5\pi d^3}{64} \times 2 = \frac{5\pi d^3}{32}.$$

$$\therefore \frac{M_{\text{TWIN}}}{M_{\text{SINGLE}}} = \frac{f \cdot Z_{yy_1}}{f \cdot Z_{aa_1}} = \frac{\frac{5\pi d^3}{32}}{\frac{\pi d^3}{32}} = \frac{5}{1}.$$

That is, the moment of resistance to bending in the plane of the bolt of two poles arranged as in Fig. 57 is FIVE times the moment of resistance of a single pole. This is interesting but purely a theoretical result. In practice it is not attained owing to the large shearing forces which are called into play and the bolts tear into the timber.

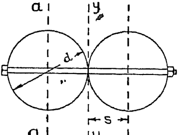


FIG. 57.

Rutter Poles (Fig. 58).—This design of compound pole makes use of the above principle but provides for the shearing forces by a series of hard-wood scarf blocks set into accurately cut slots. In this way the theoretical strength is realised; in fact, as usually constructed with 4 inches between poles at ground line and 1 inch slots the Rutter pole is about 8 times as strong as one of its members used singly. That is the ratio of lateral to longitudinal strength is 4 to 1, which is the limit imposed by the E.C. Regulations.

The shear blocks function as the web of a girder and are placed closer together in the foundation portion, because in that portion the shearing force is many times greater than in the part above ground (see p. 150).

The resistance to overturning is provided by two long timber foundation blocks, placed in the plane of the wires, and secured to the poles by bolts. It will be clear that careful fitting is necessary, and as the number of slots is large they should be cut before creosoting. The construction is therefore essentially a factory job. This type of pole is supplied by Messrs. Gabriel, Wade & English, Ltd., of Hull, and is delivered assembled, *i.e.* with the shear blocks and bolts in position, which obviates reassembling on site.

The Rutter pole has a better appearance and is stronger, size for size, than any type yet designed.

"A" Poles.—This type of pole is still largely used in this country for heavy lines. Let P (Fig. 59) be the horizontal loading

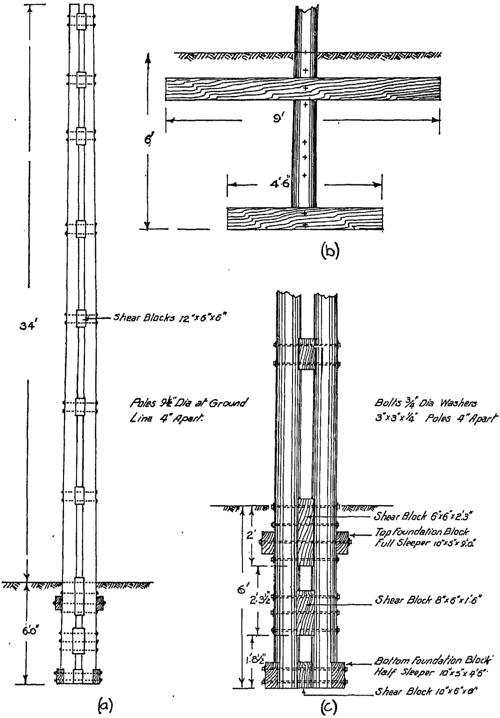


FIG. 58.—Rutter pole.

at the apex, and C and T the compressive and tensile loads on the two members.

Resolving along and at right angles to the compression member we have

$$C = P \sin \frac{\alpha}{2} + T \cos \alpha,$$

$$T \sin \alpha = P \cos \frac{\alpha}{2}.$$

If, as is usual, the spread is equal to $\frac{1}{8}$th of the height,

$$\sin \frac{\alpha}{2} = \frac{1}{16} = \cdot 0625$$

and $$\frac{\alpha}{2} = 3\tfrac{1}{2}^\circ \text{ approximately}$$

$$T = P \frac{\cos \frac{\alpha}{2}}{\sin \alpha} = \frac{\cdot 998\,P}{\cdot 1219} = 8{\cdot}2P \text{ nearly}$$

and $$C = \tfrac{1}{16}P + 8{\cdot}13P = 8{\cdot}2P \text{ also.}$$

That is, the compressive load on one member is equal to the tensile load on the other, and about 8 times the horizontal loading due to wind pressure.

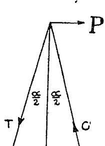


FIG. 59.

For calculation purposes it is usual to assume that, with the orthodox construction shown in Fig. 60, the compression member is equivalent to a strut fixed at both ends for which Euler's formula for the

$$\text{BUCKLING LOAD} = \frac{4\pi^2 \,.\, E \,.\, J}{L^2} = \frac{4\pi^3 \,.\, E \,.\, D^4}{64 \,.\, L^2}.$$

If J is taken for the *mean diameter* of the pole and L the distance between the point of loading and the brace block, we get a result which is roughly confirmed experimentally.

For example, consider an "A" pole made up of two standard 36 / $11\frac{1}{2}$ in. poles

$$D_m = 10 \text{ ins. and } L = 388 \text{ ins.}$$

$$\text{The BUCKLING LOAD, } C = \frac{4 \,.\, \pi^3\, 1{\cdot}2 \,.\, 10^6 \,.\, 10^4}{64 \,.\, 388^2}$$

$$= 155\,000 \text{ lb.}$$

and $$P = \frac{C}{8{\cdot}2} = \frac{155\,000}{8{\cdot}2} = 18\,900 \text{ lb.}$$

(This omits the weight of wire and pole ironwork and of the pole itself, which would add about 5 % to the compressive load.)

For a Single Pole

$$P_S = 766\,\frac{D^3}{H} = \frac{766\,.\,11{\cdot}5^3}{28\,.\,12} = 3\;470\text{ lb.}$$

$$\therefore\;\frac{P_A}{P^S} = \frac{18\;900}{3\;470} = 5{\cdot}45.$$

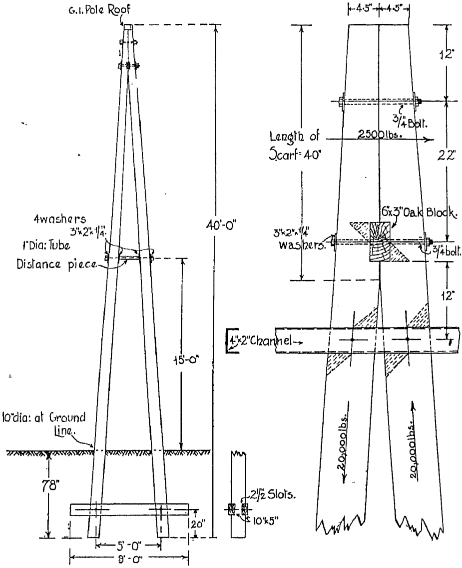


FIG. 60 (*a*). FIG. 60 (*b*).
40 feet creosoted red fir "A" pole. 10 inches diameter at groundline. 6·75 inches diameter at top.

If these calculations are repeated for the 40 feet / 10 inch "A" pole illustrated in Fig. 60 it will be found that $P_A = 7\;750$, $P_S = 2\;030$ and

$$\therefore\;\frac{P_A}{P_S} = \frac{7\;750}{2\;030} = 3{\cdot}82.$$

It cannot be pretended that there is anything very precise about the above figures. No two poles are exactly alike and the timber itself varies. The effect of the lower scarf bolt, the tie rod and the earth reaction in reducing the free length of the compression member has been neglected. Moreover, a good deal depends upon the fitting which must be well done if the full benefit of the design is to be realised in practice. Poles constructed with a spread of one-eighth of the length have been found *experimentally* (see paper by C. Wade, *J.I.E.E.*, August, 1907) to be approximately $4\frac{1}{2}$ times as strong as one of the members used singly, and in practice "A" poles are rated on this value. The following instructions may be helpful in cases where it is decided to construct "A" poles on the job.

"A" Pole Construction (see Fig. 60).—Poles should be approximately of the same dimensions and as straight as possible. If not quite straight, curvature should be at right angles to "A" plane.

1. Scarf the poles.—Cut ends off square. Arrange the poles close together side by side with the tips supported on trestles. Twist the poles into such a position that the proposed scarves will be vertical and parallel to one another. Secure the poles temporarily in this position and draw parallel chords on the tips at distances equal to one third of the tip diameter from the point of contact. Then from the tip on the inside of the poles, mark off a distance equal to six times the tip diameter and draw chalk lines on each pole from these marks to both ends of the chords drawn on the tips.

Remove the tapered portions with hand saw.

When the scarved surfaces are laid together, the poles should form an isosceles triangle with the butts at a distance apart approximately equal to one-eighth of the height. If the distance apart differs much from this value, the scarved surfaces must be planed up until the correct ratio of height to base is obtained.

2. Fit the two scarf tie bolts.—One bolt to be 1 foot and the other 3 to 4 feet (depending upon length of scarf) from tip. The poles should be temporarily secured together at the tip with carpenter's cramp and at the butt with rough timber and nails before commencing to drill the bolt holes. Use $\frac{7}{8}$ inch self-clearing auger. Make sure that holes are horizontal and pass accurately through centres of poles. 3 inch by 2 inch by $\frac{1}{4}$ inch washers to be used.

The man using the auger can only check the direction in the horizontal plane. Another man should look after the elevation.

3. Fix brace blocks.—The brace blocks should be a driving fit in the slots. The slots should not extend into the heart wood of the poles. Brace block bolts to be 20 inches from butts.

4. Fit scarf block.—Mark position of scarf block, which should be of oak 6 inch by 3 inch section and of a length equal to the diameter of the pole. The lower scarf bolt passes through the centre of scarf block. A mortice 1 inch deep is first made on each side with poles bolted together. Then separate the poles, finish slots with saw and chisel and complete fitting the block.

5. Tar all cut surfaces.—Give all mortices, slots and bolt holes a coat of hot creosote-tar mixture. Then rebolt up finally.

6. Fit roof.—To be fitted transversely to the line of wires. Top of pole beneath roof to be painted with creosote-tar mixture.

7. Fix tie rod.—Tie rod to be fixed at a distance from the butt equal to about half the height of the poles out of the ground. Take same precautions as in 2, but greater care is necessary in this case as the holes in the two poles must lie in the same horizontal plane. Distance piece of 1 inch G.I. pipe to be fitted over bolt between poles. Four 3 inch by 2 inch by $\frac{1}{4}$ inch washers to be used.

It will be found with the construction described above, that although the structure itself is $4\frac{1}{2}$ times as strong as a single pole, if held rigidly at the base, the holding power of the ordinary type of foundations, for the same depth, is not increased in anything like the same ratio. To ensure having the strength of the foundations comparable with the rest of the structure, it will be necessary to add kicking blocks, and reinforce the connection between the poles and the brace blocks.

If the foundations give appreciably, the stress distribution in the poles is considerably altered. This remark applies more particularly to poles constructed with a splay less than one-eighth the height, in which case the poles pull over and fail by simple bending.

See paper by Mr. W. B. Woodhouse, in *J.I.E.E.*, February, 1929.

It is not the usual practice to attempt theoretical calculations for the design of " A " poles, but to base the construction on a process of trial and error. It must be admitted that the factors involved are so many, and the various conditions so uncertain, that calculations unsupported by practical tests are of little use. Nevertheless, an attempt will now be made to bring out the salient features affecting the strength of the scarf joint and the holding power of the foundations.

"A" Pole. Scarf Joint.—Consider the 40 ft. / 10 in. pole illustrated in Fig. 60 (*a*). The safe working load for this pole is about 2 500 lb. (Fig. 66, p. 132) applied 2 feet from the top, and the direct load on each member with this horizontal load will be 2 500 $\times$ 8 = 20 000 lb. approximately. Actually, of course, there will be a number of wires at various distances from the top, and the centre of pressure will generally be more than 2 feet from the top. But from the nature of the problem close accuracy cannot be claimed for the calculations.

First assume two $\frac{3}{4}$-inch bolts to be used alone. The bearing lengths of the upper and lower bolts are about 5 inches and 7 inches respectively in each pole.

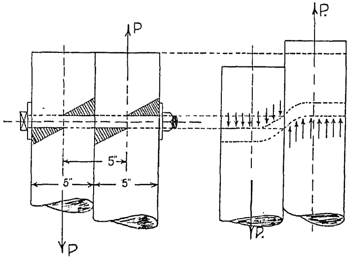


FIG. 60 (*c*). FIG. 60 (*d*).

First consider the upper bolt. If there were no flexure the joint would fail through crushing of the timber, the stress in which is roughly indicated by the shaded triangles in Fig. 60 (*c*).

In practice, however, the moment of resistance of the timber on the outside halves of the bolt assisted by the frictional force between washers and poles is greater than the moment of resistance of the bolt, and therefore when the joint fails the bolts bend from their centres, as shown exaggerated in Fig. 60 (*d*). Neglecting the small inclination with the vertical, if P = longitudinal load on each pole and f_c the maximum safe compressive stress in timber in the bolt hole (1 030 lb. / sq. in., *vide* p. 77), each of the triangular loads

$$= \left(1\ 030 - \frac{P}{5 \times \cdot 75}\right) \times \frac{5}{2} \times \frac{3}{4} \times \frac{1}{2} = \left(965 - \frac{P}{4}\right) \text{ lb.}$$

$\left(\frac{P}{5 \times \cdot 75}\right.$ = direct uniformly distributed compressive load, not shown in diagram).

The C.G. of this load is $\frac{5}{2} \times \frac{2}{3} = \frac{5}{3}$ inches from centre of bolt, therefore its moment of resistance

$$= \left(1\,030 - \frac{P}{4}\right)\frac{5}{3} \text{ lb.-ins.}$$

The moment of resistance of the bolt

$$\frac{\pi D^3}{32} f = \frac{\pi \,.\, 27 \,.\, 60\,000}{32 \times 64 \times 2{\cdot}5} = 995 \text{ lb.-ins.}$$

therefore the total MOMENT OF RESISTANCE

$$= \left\{2 \times \frac{5}{3} \times \left(1\,030 - \frac{P}{4}\right) + 995 \text{ lb.-ins.}\right\}$$

The BENDING MOMENT $= 5P$; equating one to the other we get

$$5{\cdot}82P = 4\,430 \text{ and } P = 762 \text{ lb.}$$

Working similarly the safe load on the lower bolt will be found to be 895 lb., making a total of $762 + 895 = 1\,657$ lb.

The absurdity of such a joint will be at once apparent, so we will proceed to consider the state of affairs when a 6 inch by 3 inch oak block is inserted in the scarf at the lower bolt.

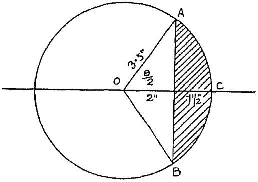


FIG. 60 (e).

The diameter of pole where block is inserted will be about 7 inches.

$$\cos\frac{\theta}{2} = \frac{2}{3{\cdot}5} = \cdot 571, \therefore \theta = 110^\circ \text{ (Fig. 60 (e)).}$$

$$\text{Length of Chord, } AB = 2 \times 3{\cdot}5 \times \sin\frac{\theta}{2} = 7 \times \cdot 82 = 5{\cdot}74 \text{ inches.}$$

$$\text{Length of Arc, } ACB = \pi \times D \times \frac{110}{360} = \pi \times 7\frac{110}{\times 360} = 6{\cdot}73 \text{ inches.}$$

$$\text{Area of Sector, } OACB = \pi \times R^2 \times \frac{\theta}{360}$$

$$= \pi \times 3{\cdot}5^2 \times \frac{110}{360} = 11{\cdot}8 \text{ sq. ins.}$$

Area of Triangle, $OAB = 2 \times \frac{5{\cdot}74}{2} = 5{\cdot}74$ sq. ins.

$\therefore$ Area of Slot $= 11{\cdot}8 - 5{\cdot}74 = 6{\cdot}06$ sq. ins.

Distance of centre of area of sector from centre O

$$= \frac{2}{3} \times \frac{\text{Radius} \times \text{length of chord}}{\text{length of arc}},$$

$$= \frac{2 \times 3{\cdot}5 \times 5{\cdot}74}{3 \times 6{\cdot}73} = 1{\cdot}99 \text{ inches.}$$

Centre of triangular area $= 2 \times \frac{2}{3} = 1{\cdot}33$ inches from O.

If centre of slot area is x inches from O,

we have $\quad 6{\cdot}06x + 5{\cdot}74 \times 1{\cdot}33 = 11{\cdot}8 \times 1{\cdot}99,$
whence $\quad x = 2{\cdot}62$ inches.

Now, if the scarf block be assumed to take the whole of the load, the average intensity of pressure on the timber in the slot will be $\frac{20\,000}{6{\cdot}06} = 3\,300$ lb. / sq. in., giving a Factor of Safety of $\frac{6\,000}{3\,300}$ $= 1{\cdot}82$, which is insufficient. The maximum permissible load on the scarf block $= \frac{6\,000}{3{\cdot}5} \times 6{\cdot}06 = 10\,400$ lb.

Required Minimum Depth of Scarf Block.—We will assume that the load of 10 400 lb. is uniformly distributed over the area of the slot.

As the centre of area of the slot is $2{\cdot}62$ inches from O, it must be $0{\cdot}62$ inch from AB, therefore :

the Bending Moment on the block $= 10\,400 \times {\cdot}62 = 12\,900$ lb.-ins.

The horizontal reaction will be a maximum at the upper and lower edges, falling away to zero at the centre, *i.e.* the load diagram will be triangular in shape, as shown in Fig. 60 (*b*), page 119.

The total permissible load on each side of the centre, if d is the depth of the block,

$$= \frac{1\,500}{3{\cdot}5} \times \frac{1}{2} \times 5{\cdot}74 \times \frac{d}{2} = 615d \text{ lb.}$$

$$\therefore \text{Moment of Resistance} = 615d \times \frac{2}{3}d = 410d^2.$$

Equating the Bending moment to the Moment of resistance we get

$$410d^2 = 12\,900,$$

and $\quad d = 5{\cdot}61$ inches.

Frictional Forces.—These may be estimated as follows :—
The tensile load on the lower scarf bolt will be about 3 000 lb., due to screwing up and on the upper bolt 3 000 lb. + $615d$ = 3450 lbs. due to the scarf block reaction. Assuming a coefficient of friction of 0·3 for wood on wood, the vertical reaction will be about $9\,450 \times \cdot 3 = 2\,835$ lb. This is somewhat indefinite, perhaps, but quite appreciable.

Help Given by Cross-Arms.—Assume a 4 inch by 2 inch channel section cross-arm to be fitted into $1\frac{1}{2}$-inch slots as shown dotted in Fig. 60 (*b*), page 119. It will be clear that any tendency of the compression member to ride upwards on the tension member, due to failure of the scarf joint, will twist the arm counter-clockwise. The stress diagram in the timber at top and bottom of slots will be triangular, as shown.

Assuming pole diameter to be 7 inches, the modulus of the slot section will be

$$Z_c = \frac{4}{15}bd^2 = \frac{4}{15} \times 1{\cdot}5 \times 2{\cdot}87^2 = 3{\cdot}29 \text{ inch units}$$

(see p. 80). If the arm bolts are 9 inches apart, and P = the maximum permissible direct load on the slots, we have roughly

$$9P = 2f_cZ_c,$$
$$\therefore P = \frac{2 \times 6\,000 \times 3{\cdot}29}{9 \times 3{\cdot}5} = 1\,250 \text{ lb.}$$

In addition to this Moment of Resistance of the slots there is a clockwise Bending Moment due to the wind pressure on the conductors, if pin insulators are used (see p. 78).

Assuming 600 lb. wind pressure on each of two conductors, and that the conductors are attached to points on the insulators 8 inches from centre of cross-arm, the bending moment due to this eccentric loading on the cross-arm $= 600 \times 8 \times 2 = 9\,600$ lb.-ins. and the vertical load on the slots $= \frac{9\,600}{9} = 1\,067$ lb., of which $\frac{1\,067}{3{\cdot}5} = 305$ lb. may be added to the vertical working load.

Similarly, if a second arm is fitted higher up where the distance between bolts is 6 inches, further additional loads of $1\,250 \times \frac{9}{6}$ $= 1\,875$ lb., and $305 \times \frac{9}{6} = 457$ lb. can be dealt with.

With two arms and a scarf block, therefore, the TOTAL LOAD which the pole top joint will support

$$= 10\,400 + 1\,250 + 305 + 1\,875 + 457 + 762 = 15\,049 \text{ lb.}$$

(762 lb. is allowed for the upper scarf bolt, but the lower one is neglected, since, in addition to the tensile stress due to tightening up, it has to withstand the reaction between the scarf block and the two members.)

This is still a good deal less than 20 000 lb., the value based upon the assumption that the pole is $4\frac{1}{2}$ times as strong as one of its members used singly, and to enable the full strength of the pole to be developed a second scarf block is really necessary if, as assumed, the load is applied 2 feet from the top.

In practice, however, as the centre of pressure would be much greater than 2 feet from the top, and friction has been neglected, there is no doubt that the Factor of Safety would be adequate with a load of 2 500 lb.

If a second scarf block is fitted it will be necessary to check the shearing strength of the pole above the block.

"A" Pole Foundations.—In practice the foundations are found to fail by the pulling out of the tension member. It is therefore proposed to assume that the brace block bolt in the compression member is a fixed point.

The figures for ground stress will be taken from Fig. 91, page 181. The upward ground reaction will be assumed to be equal to the horizontal ground reaction at the same depth. It is actually greater, but it is important to avoid any settlement. The horizontal load of 2 500 lb. applied at a point 2 feet from the top of the pole produces a BENDING MOMENT of $2\,500 \times 8 \times 60 = 1\,200\,000$ lb.-ins. on the foundations, if we neglect the small inclination of the pole with the vertical. The upper surfaces of the brace blocks are 53 inches from ground level, at which depth the safe upward bearing pressure $= 10{\cdot}5$ lb. / sq. in. approx.

The downward ground reaction will be triangular in shape, as shown in Fig. 61, and the total safe load $\frac{10{\cdot}5}{2} \times 84 \times 10 = 4\,400$ lb.

The C.G. of this load $= 84 \times \frac{2}{3} = 56$ ins. from the brace block bolt, therefore the MOMENT OF RESISTANCE $= 4\,400 \times 56 = 246\,000$ lb.-ins.

To this may be added the MOMENT OF RESISTANCE of the com-

pression member to lateral earth pressure. Since there is a large volume of disturbed soil and any appreciable movement is undesirable, we will take $k = 2\,000$ in the straight line formula given on page 107.

Then
$$M = \frac{2\,000 \times 10{\cdot}5 \times 78^3}{10 \times 12^3 \times 2{\cdot}5}$$
$$= 231\,000 \text{ lb.-ins.}$$

This implies that the compression member pivots about a point $\frac{78}{\sqrt{2}} = 55$ inches below ground level instead of 58 inches as assumed otherwise in these calculations, but this makes no material difference to the result.

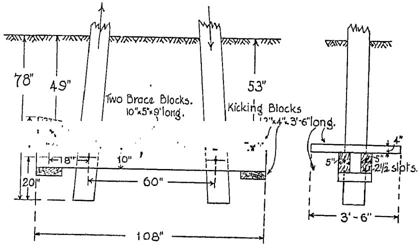


Fig. 61.

We may also add the Moment of Resistance of the slots which, estimated as explained on page 79, will be about 43 000 lb.-ins.

There may further be a little help given by the upward reaction on the brace blocks outside the compression member, but this will be very small owing to the fact that the brace blocks share the large downward load of 20 000 lb., which produces a crushing stress on the soil exceeding 30 lb. / sq. in. The maximum safe downward stress on the soil at a depth of 63 inches, assumed equal to the safe horizontal stress, is about 45 lb. / sq. in.

The total Moment of Resistance, then, which can be counted upon $= 246\,000 + 231\,000 + 43\,000 = 520\,000$ lb.-ins., which is quite inadequate.

It may be noted here, that, prior to 1923 the E.C. F. of S. for

wood poles was 10, and the maximum bending moment on these foundations would have been $1\,200\,000 \times \frac{3 \cdot 5}{10} = 420\,000$ lb.-ins. only, to deal with which a simple single brace block would have been considered quite sufficient ; and in fact proved to be so in practice. It must be pointed out, however, that after a year or so, when the earth gets consolidated, the strength of the foundations is greatly increased and may in favourable circumstances reach double the initial value when the pole is erected.

Now that the F. of S. for wood poles has been reduced to 3·5, it is obvious that more attention must be paid to the foundations, and we will now consider the effect of adding KICKING BLOCKS at the ends of the brace blocks.

The detailed calculations giving the moment of resistance due to the upward ground reaction on the brace blocks and kicking blocks at the foot of the compression member will be left as an exercise for the reader. Together with the moment of resistance of the slots it will be found to be nearly equal to the MOMENT OF RESISTANCE of the brace blocks themselves which

$$= 2\frac{bd^2f}{6} = \frac{2 \times 5 \times 100 \times 7\,800}{6 \times 3 \cdot 5} = 372\,000 \text{ lb.-ins.}$$

The moment of resistance to be provided by the kicking blocks at foot of tension member is therefore

$$1\,200\,000 - 246\,000 - 372\,000 - 231\,000 = 351\,000 \text{ lb.-ins.}$$

If the kicking blocks are 4 inches thick their upper surfaces will be 49 inches from ground level. The safe upward ground stress at this depth is about 9 lb. / sq. in., therefore the area of the kicking blocks must not be less than

$$\frac{351\,000}{78 \times 9} = 500 \text{ sq. ins.}$$

If 12 inches wide, a length of 3 feet 6 inches will do.

Load on Slots.—Working as shown on page 123 ; the area of the $2\frac{1}{2}$-inch slot is about 15·4 sq. ins., ner edge 8·66 inches, and the distance of C.G. of

slot area from inner edge 1·02 inches. Neglecting the area of the bolt itself, the compressive stress on timber in slots

$$= \frac{20\,000}{15{\cdot}4 \times 2} = 650 \text{ lb.} / \text{sq. in.}$$

[neglecting the relief due to lateral ground reaction].

The safe working stress on the timber in compression

$$= \frac{6\,000}{3{\cdot}5} = 1\,715 \text{ lb.} / \text{sq. in.}$$

and from this point of view, therefore, the slots need not be so deep. About $1\frac{1}{2}$ inches would be sufficient.

Shear Stress.—The stress tending to shear off the pole below the slots

$$= \frac{650 \times 15{\cdot}4}{8{\cdot}66 \times 15} = 77 \text{ lb.} / \text{sq. in.}$$

The maximum safe longitudinal shear stress

$$= \frac{500}{3{\cdot}5} = 143 \text{ lb.} / \text{sq. in.}$$

There is ample security here also, and we could safely place the brace blocks several inches nearer to the butts.

Twisting Moment on Brace Blocks.—The above calculations for stresses in compression and shear are only true if there is no appreciable movement of the brace block in the slots.

If we assume uniform stress distribution over the bottom of the slot, the C.G. of the slot reaction will be 1·02 inches from the inner edge, and taking the C.G. of the load on the brace block to be on its centre line there will be a TWISTING MOMENT on it = 10 000 (2·5 − 1·02) = 14 800 lb.-ins. (Fig. 62 (*a*)). Now the slot fixing is quite incapable of dealing with this. If the brace block twists appreciably the concentration of stress near the outer edge of the bottom of the slot will be so great as to crush the timber, the brace block will become loose and as the $\frac{3}{4}$-inch bolt has a safe moment of resistance of 995 lb.-ins. only the joint will fail.

It may be noted that the centre of the brace block is not the best position for the bolt in the tension member. It will be much more effective if placed well above the centre (say $2\frac{1}{2}$ inches above), but in this case a second bolt should be placed below the centre to satisfy the conditions when, owing to change of direction of wind,

the member becomes loaded in compression. Moreover, if a narrower brace block is used and housed full depth the twisting moment will be very much reduced, but reducing the size of the brace blocks will necessitate further modifications in the design. Fortunately, in the case under consideration, a considerable moment of resistance is provided by the fact that the kicking blocks are bolted to the brace blocks.

The compressive load between brace blocks and kicking blocks is indicated by the small triangles in Fig. 62 (*b*), and the safe maximum

Moment of Resistance

$$= \left\{ \left(\frac{1\,500}{2 \times 3{\cdot}5} \times \frac{5}{2} \times 12 \right) \times \frac{5}{2} \times \frac{2}{3} \right\} \times 2$$

$$= 6\,430 \times 1{\cdot}67 \times 2 = 21\,400 \text{ lb.-ins.,}$$

which is greater than necessary.

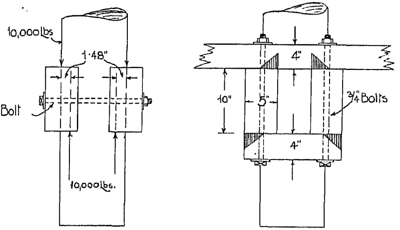


Fig. 62 (*a*) in slots. Fig. 62 (*b*) at kicking blocks.
Brace block sections.

The stress in the ¾-inch bolts securing the kicking blocks to the brace blocks allowing 3 000 lb. tension due to tightening up the nut

$$= \frac{3\,000 + 6\,430 \times \dfrac{14\,800}{21\,400}}{{\cdot}304} = 24\,500 \text{ lb.} / \text{sq. in.}$$

The maximum safe working stress $= \dfrac{65\,500}{2{\cdot}5} = 26\,000$ lb. / sq. in.

It is not proposed to pursue this matter further as it is thought that enough has been said to indicate the lines on which the strength of the foundations may be estimated.

We have neglected the loss of area of brace blocks in slots and under kicking blocks and a number of other small details, but the method of calculations will be found to give results which agree closely with those obtained by experiment on poles shortly after erection in reasonably good soil. Better results will generally be obtained when the soil gets thoroughly consolidated (say after six to twelve months).

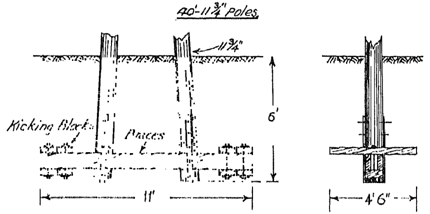


FIG. 63.—Rutter type.

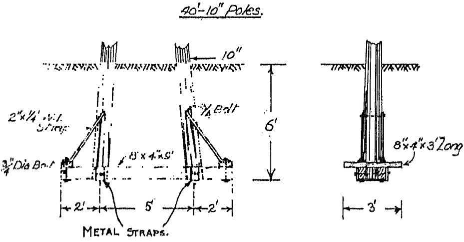


FIG. 64.—Anchora type.
Types of strengthened "A" pole foundations.

A good deal of thought has been given during the last two years to the design of satisfactory "A" pole foundations and the two designs illustrated in Figs. 63 and 64 are of interest.

Rutter "A" Pole Foundation.—Fig. 63, shows a new type of "A" pole foundation patented by Mr. Rutter. Braces are housed full depth in the poles, near the bottom, and the usual transverse kicking blocks are provided. The braces are connected to the poles

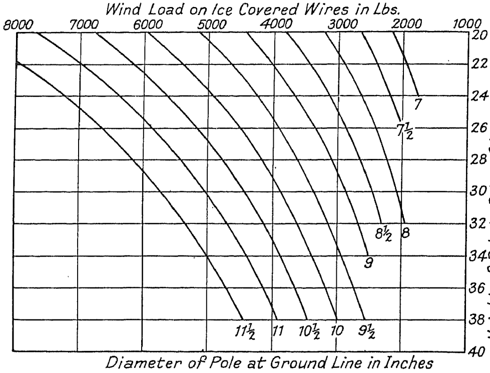


FIG. 65.—Net safe working loads. Rutter poles.

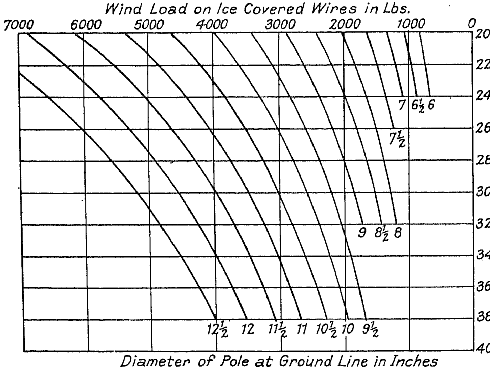


FIG. 66.—Net safe working loads. "A" poles.

by stirrup straps which are proportioned to the load both in sectional area and length, so that a sufficient number of bolts can be provided. Using narrower brace blocks housed full depth reduces the bending moment on the bolts, and incidentally the stirrup straps enable the brace blocks to be fixed nearer the butts.

Anchora "A" Pole Foundation.—Fig. 64 illustrates this type of "A" pole foundations, which has recently been patented. The special features of the design are (1) the wrought iron tie rods which transfer the upward pull from the kicking blocks to the tension member; (2) the undercutting of the earth to take the kicking

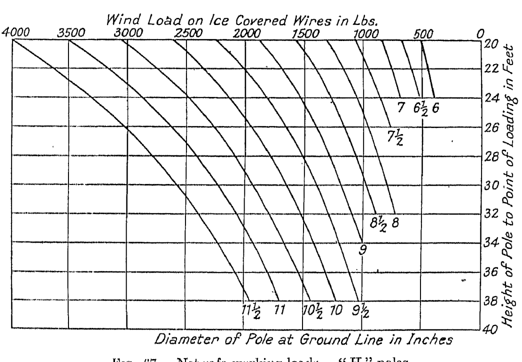


FIG. 67.—Net safe working loads. "H" poles.

blocks, thus taking a proportion of the upward load by undisturbed soil; (3) the brace blocks are situated in their most effective position, *viz.* at the pole butts (maximum depth); (4) the metal plates of channel section fitted to improve the bearing surface under the butts.

"H" Poles (Fig. 85, page 174).—"H" poles, as usually constructed with one set of trussing tackle, are not so strong laterally as "A" poles, but they are simpler to construct.

They are largely employed for terminations, junction and sectioning poles and for road and telegraph crossings where a greater ground clearance is required, owing to the longer arms which are

possible and the extra space available for dealing with conductors stay and guard wires and for fixing pole type transformers, isolating switches, cable terminating boxes, etc. Also it will frequently be necessary to use them at angles and terminals in cases where the direct compressive load is too much for a single pole.

Figs. 65, 66, and 67 give for RUTTER "A" and "H" poles respectively, the safe load that may be applied to a point 2 feet from the top of a pole, taking a modulus of rupture of 7 800 lb. per square inch and deducting the wind pressure calculated at 8 lb. per square foot, after dividing by a Factor of Safety of $3\frac{1}{2}$ as required by the E.C. Regulations.

For the "A" and Rutter poles, the wind pressure is taken on $1\frac{1}{2}$ times the projected area of one pole, and for the "H" pole $1\frac{3}{4}$ times.

The figures for RUTTER poles are obtained by calculation, allowing for the weakening due to the 1-inch slots and one $\frac{3}{4}$-inch bolt.

"A" poles are assumed to be $4\frac{1}{2}$ times and "H" poles 3 times as strong as one of the members used singly.

It is understood that these assumptions are approved by the Electricity Commissioners.

CHAPTER VIII.

IRON AND FERRO-CONCRETE POLES.

IRON POLES are not often used if wood poles are suitable and easily procurable. For the same duty the former are much more expensive than the latter, and as iron poles have to be painted periodically they cost more in maintenance.

In the colonies and India, however, climate and the white ant frequently make the use of iron poles imperative. In this country TUBULAR IRON poles are employed occasionally in residential districts for æsthetic reasons since they take up less room and lend themselves better to painting and decoration.

The British Engineering Standards Association have recently issued a specification for TUBULAR IRON AND STEEL POLES for Telegraph and Telephone Purposes (B.S.S., 134—1927) from which the following particulars have been abstracted by permission of the Association. Official copies of this specification may be obtained from the offices of the Association, 28 Victoria Street, London, S.W. 1, price 10s. 10d., post free. A good many of the standard sizes are suitable for power distribution, including 37 feet poles for working loads up to 1 000 lb.

Four types are standardised, two giving lengths up to 44 feet in two or three parts, and the other two made up of short lengths not exceeding about 8 feet each. These latter " multiple section " poles are the most suitable type for use abroad, as their handling, storage and transport are simpler.

" Type B " consists of a series of tapered steel riveted tubes, galvanised after manufacture, with a cast iron base so combined as to give the required strength and length. Any series of tubes can be nested together into a package 8 feet long, the diameter of which is equal to that of the largest tube. This method of packing avoids the necessity for any further packing and ensures economy in shipment.

To construct the pole, the bases and tubes are laid on the groun and the tubes so placed that the riveted seams appear on alternat

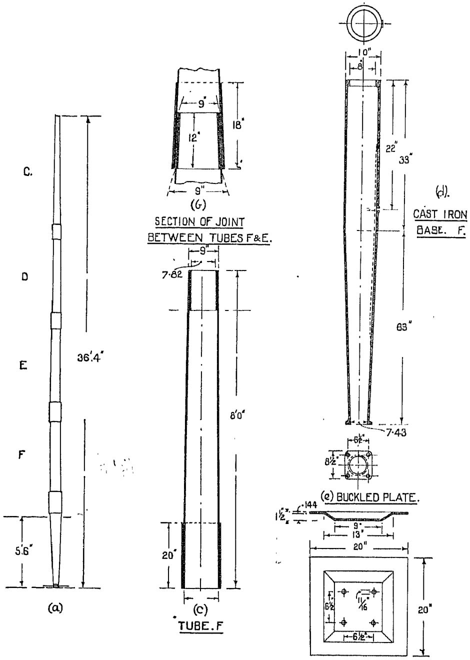


FIG. 68.—Riveted seam tapered pole in multiple sections. British standard Type B.
Test load 1 100 pounds applied 6 ins. from top.

sides. The lower tube is first driven on the base, and the secon tube driven on to the lower one, and so on, until the pole is complete

As an example, Fig. 68 (a) shows the assembly of a Type B stan

dard pole of overall length, 36 feet 4 inches (nominal 35 feet) capable of withstanding a test load of 1 100 lb. applied at a point 6 inches from the top, when buried in the ground 5 feet 6 inches. Fig. 68 (*b*) shows the joint between tubes *F* and *E*, Fig. 68 (*c*) the tube *F*, Fig. 68 (*d*) the cast iron base, and Fig. 68 (*e*) the buckled plate. The ultimate tensile strength of the steel is specified as 27-32 tons per square inch, and the elongation 20 % on an 8-inch test piece. The ultimate tensile stress of the C.I. used in the base must not be less than 9 tons / sq. in.

The yield point stress in the steel tubes, calculated from specified cantilever test loads must not be less than 20 tons / sq. in., and the C.I. Base must withstand a test load producing a calculated stress of 9 tons / sq. in. without breaking.

The test load for the assembled pole is based on the assumption that the ground does not give effective support for a distance (in the case of this particular size of pole) of 10 inches. For purposes of calculation, therefore, the " length above the ground " is taken as equal to 30 feet 10 inches + 10 inches = 31 feet 8 inches. The bending moment on the section 10 inches below ground level is therefore $1\,100 \times (380 - 6) = 411\,400$ lb.-ins. when the test load is applied.

As a matter of interest we will check the stress at two of the sections.

Maximum Stress in Steel Tube F, *just below top joint* (at fitting line).—From Fig. 68 (*a*) it will be seen that, at the section chosen, the approximate external and internal diameters of the tube are 9·0 and 8·744 inches respectively and the distance of the section from the point of application of the load = 261 inches.

The MOMENT OF RESISTANCE of section $= \pi \dfrac{D^4 - d^4}{32D} \cdot f$ in which D and d are respectively the external and internal diameters and f the maximum stress.

The BENDING MOMENT = $1\,100 \times 261$ lb.-ins.; equating one to the other we get

$$\pi \frac{D^4 - d^4}{32D} f = \frac{\pi(9^4 - 8{\cdot}744^4)}{32 \times 9} f = 1\,100 \times 261 \text{ lb.-ins.,}$$

whence $f = 37\,000$ lb. / sq. in. = 16·5 tons / sq. in., which is well within the specified figure of 20 tons / sq. in.

Stress in Cast Iron Base 10 *inch below ground level.*– Reference to Fig. 68 (*d*) will show that the cast iron base has, a the point chosen, the approximate external and internal diametei of 8·325 and 7·325 inches respectively, and the distance of th section from the point of application of the test load = 374 inche:

$$\therefore \frac{\pi(8{\cdot}325^4 - 7{\cdot}325^4)}{32 \times 8{\cdot}325} f = 1\,100 \times 374 \text{ lb.-ins.},$$

whence $f = 18\,100$ lb. / sq. in. = 8·1 tons / sq. in., which is we within the figure of 9 tons / sq. in. which the material has to witl stand to comply with the specification.

Assuming an ultimate stress of 30 tons per square inch, the maxi mum working load for this pole will be $\frac{1\,100}{2{\cdot}5} \times \frac{30}{20} = 660$ lb. applie 6 inches from the top or $660 \times \frac{380}{362} = 694$ lb. applied 2 feet from th top.

Allowing for wind pressure on the pole itself, it will carry a H.V line ($\frac{3}{8}$ inch ice) consisting of three ·05 sq. in. copper conductors an one 7/·08 earth wire with the centre of pressure 2 feet from top on a span length of 220 feet, but the wires will be nearly 6 feet highe than they need be. If the conductors are lowered 4 feet, the spa length may be 250 feet, and of course the top member "*c*" need no be more than 4 feet long.

In tropical countries the pole should be suitable for longer spans

The total weight of the pole is about 800 lb. (tube *C*, 65 ; *D*, 92 *E*, 120 ; *F*, 154 ; cast iron base, 350 lb. ; and the buckled plate 1 lb.).

The weight of an equivalent wood pole would be about 900 lb

If weight is an important consideration, it may be noted tha Type *D* poles for the same duty can be obtained in high tensil steel (up to 40 tons / sq. inch), weighing 520 lb. total, the maximun weight of any one part being 204 lb. But since the steel tubes ar buried in the ground, and no buckled plate is used, such poles shoul be set in concrete.

Foundations (see p. 105).

Bending Moment referred to apoint $\frac{66}{\sqrt{2}} = 46{\cdot}7$ inches belov ground level $= 660(364 + 46{\cdot}7) = 271\,000$ lb.-ins (Fig. 69).

MOMENT OF RESISTANCE OF GROUND $= M = \dfrac{D \, . \, k \, . \, h^3}{10}$ (p. 107).

It will be seen from Fig. 68 (d) that the average value of D below ground level is 8·6 inches. Assuming then that $k = 4\,000$,

$$M = \frac{8{\cdot}6 \times 4\,000 \times 66^3}{10 \times 12^3} = 571\,000 \text{ lb.-ins.}$$

$$\therefore \text{F. of S. against overturning} = \frac{571\,000}{271\,000} = 2{\cdot}11.$$

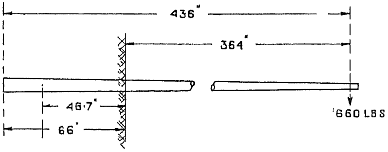


FIG. 69.

This is insufficient, but it is usual, however, to add a buckle plate, 20 inches square for the pole we are considering.

From Fig. 91, page 181, we find that the maximum pressures which the ground will withstand at a depth of 5 feet 6 inches are :

(1) Uplift at end A (Fig. 70) $= 2\,360 \times 2{\cdot}5 = 5\,900$ lb. / sq. ft.

(2) Downward at end $B = 7\,080 \times 2.5 = 17\,700$ lb. / sq. ft.

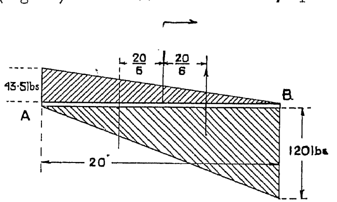


FIG. 70.

This assumes the downward pressure which the ground can support to be equal to the pressure offered to a stay block when pulled horizontally. Actually the former should be much greater than the latter.

To these figures may be added the weight of the pole, wire, ar fittings, which will be about 1 000 lb., giving a downward pressure $\dfrac{1\,000}{20 \times 20} \times 144 = 360$ lb. / sq. ft. Therefore the maximum pr sures when the ground is on the point of failure will be :—

(1) *End A*, 5 900 + 360 = 6 260 lb. / sq. ft. = 43·5 lb. / sq. in.
(2) *End B*, 17 700 − 360 = 17 340 lb. / sq. ft. = 120 lb. / sq. in.

The load diagrams on the upper and lower surfaces of the buckle plate will be as shown in Fig. 70, therefore the moment of resistance due to the plate

$$= \left(\frac{43{\cdot}5}{2} \times 20 \times 20 \times \frac{20}{6}\right) + \left(\frac{120}{2} \times 20 \times 20 \times \frac{20}{6}\right)$$
$$= 109\ 000 \text{ lb.-ins.}$$

This neglects the loss of area on the upper side of the plate due to the pole, but this introduces no appreciable error. Total moment of resistance of ground will then be 571 000 + 109 000 = 680 000 lb.-ins., and the F. of S. against overturning is increased to $\frac{680\ 000}{271\ 000} = 2{\cdot}5$ approximately.

If the buried depth is increased from 66 to 70 inches the F. of S. goes up to about 3·0.

Deflection.—It is not possible to calculate this very closely, but we can make a guess at what to expect, in the following way:

In the case of a uniform tube the deflection $\delta = \frac{PH^3}{3EJ}$ and if the tube were conical with the apex at the point of loading, $\delta = \frac{PH^3}{2EJ}$. The actual deflection will be somewhere between these two values.

Assuming the deflection to commence at the top of the lower band in tube F, then $H = 325$ inches, external diameter of tube = 10·026 inches and internal diameter = 9·77 inches approximately.

$$\therefore J = \frac{\pi(D^4 - d^4)}{64} = \frac{\pi(10{\cdot}026^4 - 9{\cdot}77^4)}{64} = 48.$$

Taking $E = 30 \,.\, 10^6$ lb. / sq. in.,

$$\delta = \frac{PH^3}{3EJ} = \frac{660 \times 325^3}{3 \times 30 \times 10^6 \times 48} = 15{\cdot}7 \text{ inches.}$$

For a conical tube the deflection equals 15·7 × 1·5 = 23·5 inches. So a rough estimate of the deflection to be expected at the maximum working load is the mean of these two values, say, 19 inches.

Channel Iron Poles.—The tubular poles described above would naturally be used if available, but in some cases abroad it

may be necessary to make up poles from such standard sections as may happen to be at hand. Channel Section is very suitable for the purpose.

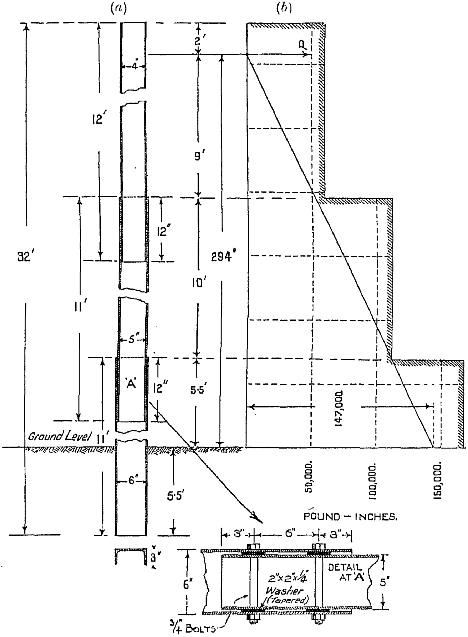


FIG. 71.—Simple channel iron pole.

Fig. 71 (*a*) shows a suggested design for a channel iron pole which is approximately equivalent in strength laterally to a 32 foot by 9 inch (*i.e.* medium) fir pole.

The pole is made up of three lengths of standard channel, one 11 feet of 6 inches by 3 inches, one 11 feet of 5 inches by $2\frac{1}{2}$ inches,

and the other 12 feet of 4 inches by 2 inches. The lengths overlap one foot and are bolted together.

A simple way of studying the strength of the pole is to draw a MOMENT OF RESISTANCE diagram (Fig. 71 (*b*)) from the figures given in Table VIII., page 71. It will be seen from this diagram that, assuming 5 feet 6 inches buried, and that the point of loading is 2 feet from the top, the pole is suitable for a BENDING MOMENT of about 147 000 lb.-ins., with a F. of S. of 2·5. Allowing for wind pressure on pole itself, the lateral load which the pole will carry

$$= \frac{147000}{24{\cdot}5 \times 12} - 21 = 500 - 21 = 479 \text{ lb.}$$

The pole is therefore suitable for a H.V. line ($\frac{3}{8}$-inch ice) with three ·05 sq. in. conductors and a 7 / ·08 earth wire on a span length of 175 feet.

The total weight of the pole is about 440 lb. and that of an equivalent wood pole 600 lb.

Ratio of Lateral to Longitudinal Strength.—(See Table VIII., p. 71.)

6 ins. × 3 ins. Channel Section $= \frac{7{\cdot}09}{1{\cdot}339} = 5{\cdot}3$ [4·57 only utilised],

5 ins. × $2\frac{1}{2}$ ins. „ „ $= \frac{4{\cdot}749}{{\cdot}95} = 5{\cdot}0$,

4 ins. × 2 ins. „ „ $= \frac{2{\cdot}532}{{\cdot}502}$ 5·05 [4·4 only utilised].

The E.C. Regulations specify a maximum ratio of 4, therefore in the unlikely event of such a pole being used in this country, the loading would have to be reduced from 500 lb. to $500 \times \frac{4}{5} = 400$ lb.

It will be noted from Fig. 71 (*b*) that the strength of the pole is determined by the strength of the 5 inch × $2\frac{1}{2}$ inch section.

Strength of Foundations.—

Bending moment referred to fulcrum (Fig. 71 (*a*)) $\frac{h}{\sqrt{2}}$ feet below ground level

$$= 500\left(24{\cdot}5 \times 12 + \frac{66}{\sqrt{2}}\right)$$
$$= 147\,000 + 23\,300 = 170\,300 \text{ lb.-ins.}$$

MOMENT OF RESISTANCE of ground (p. 107).

$$= M = \frac{Dkh^3}{10} = \frac{3 \times 4\,000 \times 66^3}{10 \times 12^3} = 200\,000 \text{ lb.-ins.}$$

$$\therefore \text{F. of S. against overturning} = \frac{200\,000}{170\,300} = 1{\cdot}17, \text{ which is insufficient.}$$

If a sole plate is attached to the foot of the pole, it will help matters, but the calculations on p. 139 show that we cannot hope for more than another 100 000 lb.-ins. from a substantial 20 inch by 20 inch sole plate. Cross blocks will therefore be necessary, and these should preferably be of concrete slabs (see p. 111 for calculations). However, it is perhaps better to set such poles in concrete. The stability can then be easily ensured and, moreover, steel embedded in concrete lasts indefinitely.

A concrete block 12 inches × 12 inches × 72 inches is suggested. The bearing surface width will then be increased to 12 inches and the depth to 72 inches.

Now, although a slight movement in the ground is unobjectionable when simple wood and iron poles are planted direct in the ground, it is advisable to ensure as far as is reasonably possible that there shall be no movement whatever of a concrete foundation. This is of greater importance in the case of lattice girder structures than in the simple pole under consideration, but it is recommended that in all cases when calculating the moment of resistance of the lateral earth reaction to concrete pole foundations the value of k should be taken as 2 000 in good soil.

The MOMENT OF RESISTANCE will then be

$$M = \frac{Dkh^3}{10} = \frac{12 \,.\, 2\,000 \,.\, 72^3}{10 \,.\, 12^3} = 518\,000 \text{ lb.-ins.}$$

$$\text{and the F. of S. against overturning } \frac{518\,000}{170\,300} = 3{\cdot}0.$$

This neglects the small moment of resistance due to unsymmetrical earth pressure under the block.

Concrete Pole Foundations.—The concrete should be composed of clean gravel (or ballast) or hard broken brick or stone, with sharp clean sand mixed with Portland cement in sufficient

proportions to fill the interstices of the coarse material. The mixtures usually employed are :—

1 cement, 5 sand, 10 gravel or broken stone (graduated) ; or
1 cement, 4 sand, 6 broken stone (3 inch to 2 inch mesh).

The gap space with gravel (pebbles all sizes from $2\frac{1}{2}$ inches to $\frac{1}{4}$ inch) is about 35 % and with broken stone if graduated to include the same sizes it is about the same. If the broken stone is larger (3 inch to 2 inch mesh) the gap space will be larger and it is therefore not so economical in cement.

The weight of materials in *lb. per cubic foot* may be taken as follows :—

Cement 90, sand 90, gravel 110, concrete 135. It must not be overlooked when estimating that the sum of the volumes of the constituents before mixing is some 40 to 50 % greater than the volume of the resulting concrete.

A suitable natural mixture of gravel and sand can often be obtained on site.

To make the concrete, the cement is first well mixed with the sand, dry, then water is added, mixing all the while until the consistency of moist earth is reached. The aggregate of broken stone or gravel is then added and the whole well mixed.

The filling should be done in 6-inch layers which must be well rammed until a layer of water appears on the surface.

If the work is well done a compressive stress of about 1 700 lb. / sq. in. can be counted upon in 30 days after setting, and it is therefore quite unnecessary to use richer mixtures.

It is most important to see that no earth gets mixed with the concrete, as its strength may thereby be seriously weakened.

The concrete should extend six inches or so above the ground and the top should be sloped off a little to prevent rain from settling. The top surface should be faced with a 1 : 2 cement mortar.

Compound Channel Poles.—For larger loads, compound channel poles may sometimes be found useful. A simple example will be considered, consisting of two of the channel iron poles described above arranged as in Figs. 72 and 73 (*a*) with 12 inches between backs of 6 inch by 3 inch channels.

The information in the following Table XV. will be required in addition to that given in Table VIII., page 71.

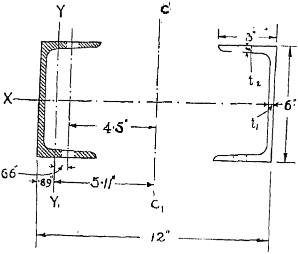


FIG. 72.

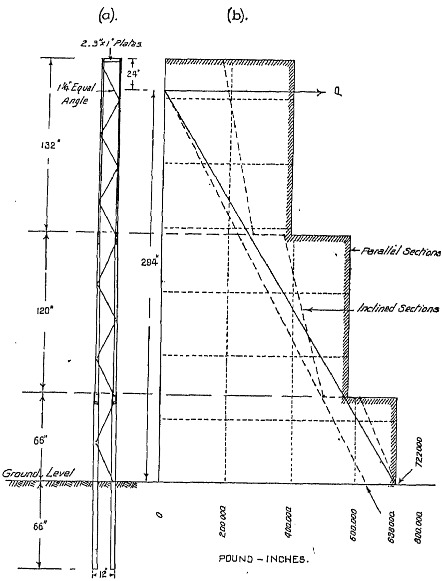


FIG. 73.—Compound channel iron pole.

TABLE XV.—[*B.S. Spec. No.* 6—1924.]

Channel Section.	Distance of C.G. from Back of Channel, ins.	t_1, ins.	t_2, ins.
4×2	·599	·24	·31
$5 \times 2\frac{1}{2}$	·773	·25	·38
6×3	·890	·25	·38

Strength of 6 inch × 3 inch Twin Channel.

$$J_{cc_1} = J_{yy_1} + \text{A.S.}^2 \text{ (Fig. 72).}$$

Loss of area due to two $\frac{1}{2}$-inch brace bolts (or rivets)

$$= \cdot 5 \times \cdot 38 \times 2 = \cdot 38 \text{ sq. in.}$$

$$\therefore \text{ Reduction in } J_{yy_1} = \cdot 38 \times \cdot 66^2 = \cdot 165$$

and $\quad$ Reduction in $\text{A.S.}^2 = \cdot 38 \times 4\cdot 5^2 = 7\cdot 69$,

both values being approximate only.

$$\therefore \text{ Nett } J_{cc_1} = (2\cdot 825 - \cdot 165) + (3\cdot 65 \times 5\cdot 11^2 - 7\cdot 69)$$

$$= 90\cdot 22 \text{ inch units for each channel}$$

$$\therefore \text{ Total } J_{cc_1} \text{ for compound section}$$

$$= 90\cdot 22 \times 2 = 180\cdot 44$$

$$\therefore\ Z = \frac{180\cdot 44}{6} = 30\cdot 07 \text{ inch units.}$$

Allowing $\quad f = 60\,000$ lb. / sq. in. and F. of S. $= 2\cdot 5$.

Safe $\quad M = fZ_{cc_1} = \dfrac{60\,000 \times 30\cdot 07}{2\cdot 5} = 722\,000$ lb.-ins.

Working similarly it will be found that $M = 576\,000$ and $388\,000$ lb.-ins. for the 5 inch by $2\frac{1}{2}$ inch and the 4 inch by 2 inch twin channels respectively.

The Moment of Resistance diagram is given in Fig. 73 (*b*), from which it will be seen that if the pole is set 5 feet 6 inches in the ground it will be suitable for a lateral load applied 2 feet from the top of

$$\frac{722\,000}{24\cdot 5 \times 12} = 2\,460 \text{ lb.}$$

It is therefore approximately equivalent in strength to a 32 feet by 9 inch wood "A" pole.

Ratio of Lateral to Longitudinal Strength.

$$6 \text{ ins.} \times 3 \text{ ins.} \begin{cases} (a)\ \textit{Available}\ \dfrac{722\,000}{170\,160 \times 2} = 2{\cdot}12 \\ (b)\ \textit{Utilised}\qquad\qquad\qquad 2{\cdot}12 \end{cases}$$

$$5 \text{ ins.} \times 2\tfrac{1}{2} \text{ ins.} \begin{cases} (a)\ \textit{Available}\ \dfrac{576\,000}{114\,000 \times 2} = 2{\cdot}53 \\ (b)\ \textit{Utilised}\ \dfrac{572\,000}{114\,000 \times 2} = 2{\cdot}51 \end{cases}$$

$$4 \text{ ins.} \times 2 \text{ ins.} \begin{cases} (a)\ \textit{Available}\ \dfrac{388\,000}{60\,770 \times 2} = 3{\cdot}20 \\ (b)\ \textit{Utilised}\ \dfrac{260\,000}{60\,770 \times 2} = 2{\cdot}14 \end{cases}$$

The design does not therefore make the most economical use of the sections. The distance between backs of channels may be increased to 20 inches nearly without exceeding the ratio of lateral to longitudinal strength of 4 to 1 allowed by the regulations, and the working load may be increased accordingly.

The above calculations assume the two members to be parallel to one another, but in practice it is usual to incline them towards each other, mainly for æsthetic reasons. The moment of resistance diagram for the case in which the members are inclined, with 12 inches between backs of channels at the ground line and 8 inches at the top is shown dotted in Fig. 73 (*b*). With this arrangement it will be seen that the working load must be reduced to $\dfrac{638\,000}{294}$ $= 2\,170$ lb. We will, however, continue our consideration of the parallel arrangement.

Bracing Required Above Ground.—A suggested arrangement of the bracing is as follows: on each side of pole five diagonals in the 4 inch × 2 inch bay, four in the 5 inch × $2\frac{1}{2}$ inch and two in the 6 inch × 3 inch. The free lengths of the diagonals will then be about 25·5 inches in the 4 inch × 2 inch bay, 29·5 inches in the 5 inch × $2\frac{1}{2}$ inch and 29·5 inches in the 6 inch × 3 inch. Fig. 73 (*a*) shows the diagonals on one side only. The diagonals must be designed to take the shearing load, *viz.* 2 460 lb.

Distance between centres of rivets is 9 inches approximately. Therefore the LOAD ON DIAGONALS

$$= \frac{2\,460}{2 \cos \alpha} = \frac{2\,460 \times 29{\cdot}5}{2 \times 9} = 4\,030 \text{ lb.}$$

We will use $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch $\times$ $\frac{1}{4}$ inch equal angle, for which the least radius of gyration $k = \cdot 29$,

$$\therefore \frac{l}{k} = \frac{29\cdot 5}{\cdot 29} = 101\cdot 7.$$

Using Euler's formula (see p. 74) and a F. of S. of 2·5, the SAFE COMPRESSIVE LOAD

$$= \frac{12 \,.\, 10^7 \,.\, A}{\left(\frac{l}{k}\right)^2} = \frac{12 \times 10^7 \times \cdot 687}{(101\cdot 7)^2} = 8\,000 \text{ lb.}$$

Size of Rivet.—In addition to shear stress there will be a tensile stress in the rivet due to pulling up on contraction, and also a certain amount of stress due to bending. The F. of S. should therefore be based upon the elastic limit.

If d = dia. of rivet required, we have

$$\frac{\pi d^2}{4} \times 27\,000 = 4\,030 \times 2\cdot 5,$$

and $$d = \cdot 69 \text{ in.}$$

A $\frac{11}{16}$-inch rivet will therefore be necessary, and consequently the calculations given above for strength of channels should be repeated, as they were based on $\frac{1}{2}$-inch rivets.

The reduction, in strength however, will only be about 4 % and it is proposed to neglect it here.

Tensile Stress in Diagonals.—The alternate diagonals will be in tension. Allowing for loss of area due to $\frac{11}{16}$-inch rivet, the nett sectional area $= \cdot 526 - (\cdot 688 \times \cdot 1875)$

$$= \cdot 526 - \cdot 129 = \cdot 397 \text{ sq. in.}$$

$$\therefore \text{TENSILE STRESS} = \frac{4\,030}{\cdot 397} = 10\,150 \text{ lb. / sq. in.}$$

The E.C. require a F. of S. of 2·5 on the Elastic limit *i.e.* a limiting stress of

$$\frac{36\,000}{2\cdot 5} = 14\,400 \text{ lb. / sq. in.}$$

The $1\frac{1}{2}$ inch $\times$ $1\frac{1}{2}$ inch $\times$ $\frac{3}{16}$-inch diagonal is therefore amply strong enough both in tension and compression.

Buckling Strength of Channels.—It is advisable to arrange

the diagonals alternately on the two sides of pole to reduce the free length of the channel considered as a strut.

Consider, for example, the lower end of the 4 inch × 2 inch channel.

The free length = 24 inches approximately and the distance between the centres of gravity of the two channel sections = 9·8 in. The B.M. at the working load = 260 000 lb.-ins. (see Fig. 73 (*b*)), therefore the vertical compressive loading

$$= \frac{260\,000}{9{\cdot}8} = 26\,500 \text{ lb.}$$

To this should be added one half the dead weight load of the pole, pole fittings and conductors, which would be about 2 000 lb. in all, therefore the total compressive loading = 26 500 + 1 000 = 27 500 lb. For 4 inch × 2 inch channel, A = 2·085 sq. ins. and k (lesser value) = ·703.

$$\therefore \text{ Buckling Load, } P = \left(46\,000 - 166\frac{24}{\cdot 703}\right) \times 2{\cdot}085$$

$$= 84\,000 \text{ lb.}$$

$k = \cdot 581$

and the F. of S. $= \frac{84\,000}{27\,500} = 3{\cdot}06.$

Forces Below Ground.—It is the usual practice to set poles of this type in concrete. For calculation purposes the concrete is supposed to be a homogeneous body with a definite elastic modulus, in which case the stress distribution will be as represented by the area *OABCD* in Fig. 74 (*b*), page 150, the pole being supposed to pivot about the point O, its centre point below ground.

If f_c is the maximum compressive stress in the concrete, then the areas of the triangles *OAB* and *OCD* will be each equal to $\frac{f_c \times 6 \times 33}{2}$ lb. The C.G. of these triangles will be $\frac{2}{3} \times 33$ inches from *O*, therefore the Moment of Resistance of Concrete

$$= \frac{f_c \times 6 \times 33 \times 44}{2} \text{ lb.-ins.}$$

This must be equal to the Bending Moment due to the Load which

$$= 2\,460 \times (294 + 33),$$

$$\therefore f_c = \frac{2\,460 \times 327 \times 2}{6 \times 33 \times 44} = 185 \text{ lb. / sq. in.}$$

The concrete will stand 1 700 lb. / sq. in. and there is, therefore, a high factor of safety in this respect.

Bracing Required Below Ground.—The direct horizontal loading at the extreme points A and C (Fig. 74 (b)) will be $185 \times 6 =$ 1 110 lb. per inch run due to the reaction of the concrete. Since the horizontal forces must themselves balance as well as their moments

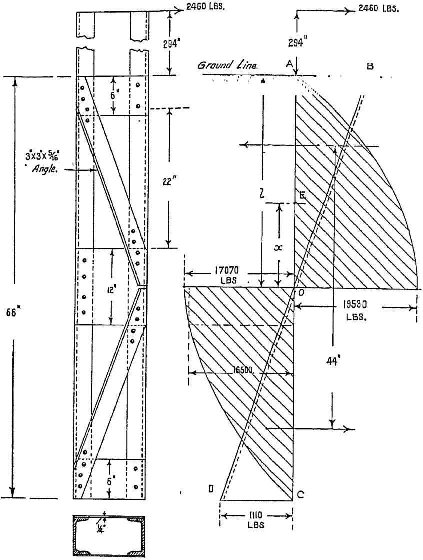


FIG. 74.—Foundation portion of compound channel iron pole. (See Fig. 73.)

we must also consider the pole top loading which may be taken as ıiform load of $\frac{2\,460}{66} = 37$ lb. per inch run. Therefore the total t $A = 1\,110 + 37 = 1\,147$ lb. and at $C = 1\,110 - 37 =$ per inch run. The loading decreases uniformly down to).

If the total load on O.A. $= W + \frac{P}{2}$,

then the load on a length O.E. $= W\frac{x^2}{l^2} + \frac{P \cdot x}{2 \cdot l}$.

$\therefore$ SHEARING FORCE AT E (Fig. 74 (b)).

$$= W\left(1 - \frac{x^2}{l^2}\right) + \frac{P(l - x)}{2l}.$$

Now W $= \frac{1\,110 \times 33}{2} = 18\,300$ lb.,

$\therefore$ Substituting known values in above equation the shearing force at any point x inches above O

$$= 18\,300\left(1 - \frac{x^2}{33^2}\right) + \frac{2\,460(33 - x)}{2 \times 33}.$$

At the point O, the maximum values occur, *viz.* 18 300 + 1 230 = 19 530 lb. from right to left and 18 300 — 1 230 = 17 070 lb. from left to right below O. The shearing force diagram is shown shaded in Fig. 74 (b).

It will be obvious that we need only to consider the lower value.

Now if the pole is set in concrete and the interior spaces are well filled and rammed, the braces will be relieved of these very large shearing forces, but we will assume that the interior is empty. A possible method of bracing to meet this latter condition is shown in Fig. 74 and consists of two 6 inch $\times$ $\frac{1}{4}$ inch plates at ground line, two 6 inch $\times$ $\frac{1}{4}$ inch plates at butt, two 12 inch $\times$ $\frac{1}{4}$ inch plates at centre; and four 3 inch $\times$ 3 inch $\times$ $\frac{3}{8}$ inch diagonals (two only shown in Fig. 74).

The free length of diagonals $= \sqrt{9^2 + 22^2} = 24$ inches approx.
For $3 \times 3 \times \frac{3}{8}$ inch equal angle, $A = 2{\cdot}11$ and $k = {\cdot}58$

$$\frac{l}{k} = \frac{24}{{\cdot}58} = 41{\cdot}3,$$

$$\therefore \text{BUCKLING LOAD} = (46\,000 - 166 \times 41{\cdot}3)2{\cdot}11$$
$$= 82\,600 \text{ lb.}$$

The working load on each diagonal

$$= \frac{17\,070 \times 24}{2 \times 9} = 22\,800 \text{ lb.}$$

$$\therefore \text{F. of S.} = \frac{82\,600}{22\,800} = 3{\cdot}62.$$

Rivets.—Assume $\frac{3}{4}$-inch rivets are used, and let n be the numb required, then $\frac{\pi d^2}{4} \times n \times 27\,000 = 22\,800 \times 2{\cdot}5$, and $n = 4{\cdot}8$.

Therefore five $\frac{3}{4}$-inch rivets would be required. It is, howeve more convenient to use four rivets, and these must be $\frac{13}{16}$ inc in diameter.

Stress in Diagonal in Tension.—Allowing for loss of are due to one $\frac{13}{16}$-inch rivet, the effective cross-sectional area (diagonal

$$= 2{\cdot}11 - ({\cdot}375 \times {\cdot}8125) = 1{\cdot}806 \text{ sq. ins.}$$

$$\therefore \text{TENSILE STRESS} = \frac{22\,800}{1{\cdot}806} = 12\,600 \text{ lb.} / \text{sq. in.}$$

This is well below 14 400 lb. / sq. in., the value permitted by th E.C. Regulations.

The Factors of Safety so determined are on the pessimistic side since, although we have neglected the somewhat eccentric loading o the diagonals, we have also neglected the help given by the $\frac{1}{4}$-incl plates.

Many other arrangements of the bracing will suggest themselves but it will be clear that if the pole is set in the ground in such a way that stability is to be ensured by horizontal reactions, then th shearing forces in the foundations require special consideration.

The plates at the ground line will not help much except to stiffe up the structure, especially during handling and erection, but th two 12-inch plates at the centre will take an appreciable share of th shearing load.

Ground Reactions.—Assume a concrete block 24 inches × 42 inches × 72 inches, as shown in Fig. 75.

First consider the ground reaction under the block. The maximum rupture intensity at a depth of 72 inches $= \frac{8\,420 \times 2{\cdot}5}{144} =$ 146 lb. / sq. in. (Fig. 91, p. 181). The approximate weight of pole and conductors will be 2 000 lb. and of the concrete block 6 000 lb. therefore the direct compressive stress

$$= \frac{8\,000}{24 \times 42} = 7{\cdot}93 \text{ lb.} / \text{sq. in.}$$

The load diagram is then as shown in Fig. 75 and the MOMENT OF RESISTANCE due to this load

$$= \frac{146 - 7{\cdot}93}{2} \times 24 \times 42 \times 4 = 278\,000 \text{ lb.-ins.}$$

The LATERAL GROUND REACTION, taking

$$k = 2\,000, = \frac{k \,.\, D \,.\, h^3}{10} = \frac{2\,000 \,.\, 42 \,.\, 72^3}{10 \,.\, 12^3} = 1\,815\,000 \text{ lb.-ins.}$$

therefore the TOTAL MOMENT OF RESISTANCE = 278 000 + 1 815 00 = 2 093 000 lb.-ins.

The BENDING MOMENT on the block

$$= 2\,500 \left(294 + \frac{72}{\sqrt{2}}\right) = 862\,000 \text{ lb.-ins.}$$

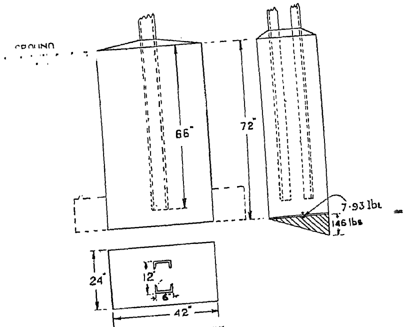


FIG. 75.

∴ FACTOR OF SAFETY against overturning

$$= \frac{2\,093\,000}{862\,000} = 2{\cdot}43.$$

Therefore the size of concrete block just about meets requirement in average good soil. It will generally be found that a rectangula block with the longer side towards the lateral loading, is more ecc nomical than a block of square section. In this case a 36 inch × 3 inch × 72 inch block would provide about the same ground reactio but its volume is 30 % greater. It may sometimes be advantageou to reduce the cross-section and increase the depth, since the later ground reaction is proportional to the cube of the depth. A furthe economy in material might be realised by adding feet to the base

the block (shown dotted in Fig. 75) to take advantage of the superin cumbent earth pressure thereon.

Ferro-Concrete Poles.—Ferro-concrete poles have not bee used to any extent in this country, but they have been used a goo deal on the Continent and in America. Their great weight is disadvantage, some designs being 3 to 4 times as heavy as equiva lent wood or iron poles, although the ratio has been brought down t 2 in some cases, notably in the "Marriot" design of pole, which i manufactured in this country. They require more care in handlin than wood or steel poles and are frequently stressed more durin transport and erection than they are likely to be subsequently i service. They have to be constructed on or near the site, and this combined with their great weight, makes their use impracticabl in difficult country.

At the present time they cannot compete with wood poles fron a first cost point of view, but since they are practically everlastin and their maintenance charges negligible, and as the supply o timber is unlikely to keep pace with the demand in the near future they may have to be seriously considered for distribution purposes in competition with iron.

The design and construction of ferro-concrete poles should no be lightly undertaken, unless the engineer has had experience o ferro-concrete work and has time to consider the matter carefully.

The concrete mixture should consist of 1 Portland cement, 2 sand, 4 broken stones or gravel (pass $\frac{3}{4}$-inch mesh but retained by $\frac{3}{16}$-inch mesh). When well made, the crushing strength of such a mixture is about 1 000 lb. / sq. in. in 7 days, 2 500 lb. in one month, 3 000 lb. in three months and 3 500 lb. in six months. The weigh is about 140 lb. per cubic foot.

Round reinforcing bars are invariably used, and, within limits, a large number of small bars are better than a few larger ones owing to the larger surface they provide for adhesion between steel and concrete. Angle and tee sections must not be used, as although they provide a large surface area compared with their cross-section it is practically impossible to ensure that the concrete is packed securely in the corners. The reinforcement should be covered with concrete to a depth which need not exceed 1 inch, but should be at least equal to the diameter of the bar. The bars should be free from loose rust.

To illustrate the principles involved, a simple example of a

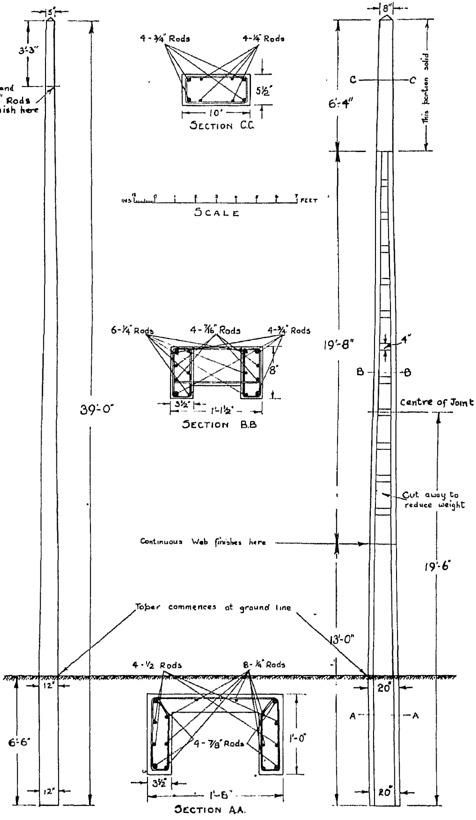


FIG. 76.—Ferro-concrete pole.

successful design, shown in Fig. 76, will now be briefly considered. The following assumptions are made :—

(1) The pole is subjected to pure bending and the total compressive load on one side of the neutral axis is equal to the total tensile load on the other.

(2) Plane sections remain plane after bending.

(3) For the concrete, as well as for the steel, the stress is proportional to the strain.

(4) There is no slip between the concrete and the steel. This is true except in the case of very short columns ; also the coefficients of expansion of steel and concrete are about the same, and therefore no appreciable stresses are set up by ordinary changes in temperature.

(5) The whole tensile load is taken by the steel reinforcement.

(6) The area of the reinforcement is so small that we may assume the stress constant over it.

The following constants will be taken :

Ultimate tensile stress	Steel	65 000	lb. / sq. in.
,, ,, ,,	Concrete	250	,,
Ultimate compressive stress	Steel	55 000	,,
,, ,, ,,	Concrete	2 500	,,
Modulus of elasticity	Steel	$30 . 10^6$	,,
,, ,,	Concrete	$2 . 10^6$	,,
Safe maximum adhesion between concrete and steel		100	,,

In structural work it is usual to design for a Factor of Safety of 2 for steel based on the elastic limit, and a F. of S. of 4 for concrete based on the ultimate compressive stress. We will assume, however, that the bending theory holds up to the ultimate stress, and allow a F. of S. of 3·5 on the structure as a whole, as required by the E.C. Regulations.

The following notation will be used :—

Tensile stress	Steel	f_{st}	Concrete	f_{ct}
Tensile load	,,	T_s		
Compressive stress	,,	f_{sc}	Concrete	f_{cc}
Compressive load	,,	C_s	,,	C_c
Modulus of elasticity	,,	E_s	,,	E_c
Area of cross section	,,	A_s	,,	A_c

Fig. 77 (*a*) shows a cross-section at the ground line of the pole under consideration. For simplicity we will neglect the web portion and the eight $\frac{1}{4}$-inch rods.

To calculate the strength of the pole we must first find the neutral axis, NN'. Let this be x inches from the edge of section on compressive side.

Then, as there is to be no slip, we have (Fig. 77 (*b*))

$$\frac{\text{Maximum compressive strain in concrete}}{\text{Compressive strain in steel}} = \frac{AA^1}{CC^1} = \frac{AS}{CS} = \frac{x}{x - 1{\cdot}3},$$

i.e.
$$\frac{\dfrac{f_{cc}}{E_c}}{\dfrac{f_{sc}}{E_s}} = \frac{x}{x - 1{\cdot}3}.$$

Now
$$\frac{E_s}{E_c} = \frac{30 \,.\, 10^6}{2 \,.\, 10^6} = 15,$$

$$\therefore f_{sc} = 15 f_{cc}\left(1 - \frac{1{\cdot}3}{x}\right),$$

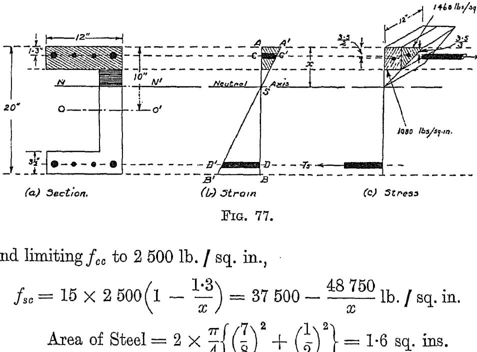


FIG. 77.

and limiting f_{cc} to 2 500 lb. / sq. in.,

$$f_{sc} = 15 \times 2\,500\left(1 - \frac{1{\cdot}3}{x}\right) = 37\,500 - \frac{48\,750}{x} \text{ lb. / sq. in.}$$

$$\text{Area of Steel} = 2 \times \frac{\pi}{4}\left\{\left(\frac{7}{8}\right)^2 + \left(\frac{1}{2}\right)^2\right\} = 1{\cdot}6 \text{ sq. ins.}$$

$\therefore$ TOTAL COMPRESSIVE LOAD ON REINFORCEMENT

$$= C_s = 1{\cdot}6\left(37\,500 - \frac{48\,750}{x}\right) = \left(60\,000 - \frac{78\,000}{x}\right) \text{ lb.}$$

Similarly tensile stress in steel on tension side

$$=f_{st}=37\,500\,\frac{DD^1}{AA^1}=37\,500\,\frac{DS}{AS}=37\,500\left(\frac{18{\cdot}7}{x}-1\right)$$

$$=\left(\frac{700\,000}{x}-37\,500\right)\text{ lb. / sq. in.}$$

∴ Total Tensile Load on Reinforcement

$$=T_s=1{\cdot}6\left(\frac{700\,000}{x}-37\,500\right)=\left(\frac{1\,120\,000}{x}-60\,000\right)\text{ lb.}$$

We must now find the compressive load on the concrete. The stress at the outer edge of flange $= 2\,500$ lb. / sq. in. and at the inner edge $= \left(2\,500 \times \frac{x-3{\cdot}5}{x}\right)$ lb. / sq. in.

The average stress is the mean of these two values, *viz.*

$$\frac{2\,500+\dfrac{2\,500(x-3{\cdot}5)}{x}}{2}=\left(2\,500-\frac{4\,370}{x}\right)\text{ lb. / sq. in.}$$

Area of concrete flange $= 3{\cdot}5 \times 12 = 42$ sq. ins. (neglecting small loss of area due to reinforcement).

∴ Total Compressive Load on Concrete

$$=C_c=42\left(2\,500-\frac{4\,370}{x}\right)=\left(105\,000-\frac{183\,750}{x}\right)\text{ lb.}$$

Now by assumption $C_s + C_c = T_s$, *i.e.*

$$60\,000-\frac{78\,000}{x}+105\,000-\frac{183\,750}{x}=\frac{1\,120\,000}{x}-60\,000.$$

Whence $\quad x = 6{\cdot}15$ inches.

$$f_{sc}=37\,500-\frac{48\,750}{6{\cdot}15}=29\,570\text{ lb. / sq. in.}$$

$$C_s=29\,570\times1{\cdot}6=47\,400\text{ lb.}$$

$$f_{st}=\frac{700\,000}{6{\cdot}15}-37\,500=76\,500\text{ lb. / sq. in.}$$

(This stress is too great, but we will continue the calculations and ow for this later.)

$T_s = 76\ 500 \times 1{\cdot}6 = 122\ 500$ lb.
f_c at outer edge of concrete flange $= 2\ 500$ lb. / sq. in.

$$f_c \text{ at inner edge of concrete flange} = 2\ 500 \times \frac{x - 3{\cdot}5}{x}$$

$$= 2\ 500 \times \frac{6{\cdot}15 - 3{\cdot}5}{6{\cdot}15} = 1\ 080 \text{ lb. / sq. in.}$$

$$C_c = 42 \times 1\ 080 + 42 \times \frac{2\ 500 - 1\ 080}{2} = 75\ 100 \text{ lb.}$$

(See Fig. 77 (*c*).)

Total compressive load $= C_s + C_c = 47\ 400 + 75\ 100 = 122\ 500$ lb.

Moment of Resistance.—Let the centre of pressure of the compressive loading be y inches from the outer edge of concrete flange, then taking moments about this edge, we have, dividing the stress diagram for the concrete into rectangular and triangular portions (Fig. 77 (*c*)),

$$122\ 500y = 47\ 400 \times 1{\cdot}3 + 1\ 080 \times 42 \times \frac{3{\cdot}5}{2} + \frac{1\ 420}{2} \times 42 \times \frac{3{\cdot}5}{3}$$

$$= 61\ 600 + 79\ 400 + 34\ 800.$$

$$\text{Whence } y = \frac{175\ 800}{122\ 500} = 1{\cdot}43 \text{ inches.}$$

∴ *Centre of compressive loading* $= 6{\cdot}15 - 1{\cdot}43 = 4{\cdot}72$ inches from neutral axis.

Now *centre of tensile loading* $= 20 - 1{\cdot}3 - 6{\cdot}15 = 12{\cdot}55$ inches. from neutral axis.

∴ *Arm of resisting couple* $= 4{\cdot}72 + 12{\cdot}55 = 17{\cdot}27$ inches.
and Moment of Resistance $= 122\ 500 \times 17{\cdot}27$
$= 2\ 120\ 000$ lb.-ins.

But this based on $f_{st} = 76\ 500$ lb. / sq. in., whereas the ultimate strength is assumed to be 65 000 lb. / sq. in. only. The moment of resistance, therefore, must not exceed

$$2\ 120\ 000 \times \frac{65\ 000}{76\ 500} = 1\ 800\ 000 \text{ lb.-ins.,}$$

and allowing a F. of S. of 3·5 the Bending Moment must not exceed $\frac{1\ 800\ 000}{3{\cdot}5} = 515\ 000$ lb.-ins.

The gross maximum working load at a point 2 feet from top of pole (*i.e.* 30·5 feet from ground level)

$$= \frac{515\ 000}{30{\cdot}5 \times 12} = 1\ 410 \text{ lb.}$$

Allowing for wind pressure on pole, the nett safe working load due to wind on wires $= 1\ 410 - 140 = 1\ 270$ lb.

The pole is approximately equivalent to a 40 foot / 8 inch "A" pole. In the above treatment we have neglected the direct compressive loading due to the dead weight of the pole and conductors, which would together be about 5 000 lb. The cross-sectional area of the concrete $= 116{\cdot}5$ sq. ins. and the compressive stress, if assumed to be taken wholly by the concrete, would be increased by

$$\frac{5\ 000}{116{\cdot}5} = 45 \text{ lb. / sq. in.}$$

On the other hand, owing to the limit imposed by the strength of the steel on the tension side, the maximum working compressive stress in the concrete due to bending is $\frac{2\ 500}{3{\cdot}5} \times \frac{65}{76{\cdot}5} = 607$ lb. / sq. in. only, instead of $\frac{2\ 500}{3{\cdot}5} = 715$ lb. / sq. in., which is the safe maximum; moreover, the eight $\frac{1}{4}$-inch rods have been neglected, and at the end of six months the strength of the concrete will have increased by 40 %.

Stress in Concrete on Tension Side.—We have neglected the tensile strength in the concrete in our calculations, but if, as we have assumed, there is no slip between the steel and the concrete, there must be a tensile strain in the concrete equal to the tensile strain in the steel.

If $$f_{st} = \frac{65\ 000}{3{\cdot}5} \text{ lb. / sq. in.}$$

then $$f_{ct} = \frac{65\ 000}{3{\cdot}5} \times \frac{2\,.\,10^6}{30\,.\,10^6} = 1\ 240 \text{ lb. / sq. in.}$$

This is an extreme figure, since in the initial stages the concrete takes a part of the tensile load.

Now the ultimate tensile stress of concrete is only about 250 lbs. / sq. in. Hence it is evident that in service the concrete cracks on the tension side, but owing to the adhesion between the

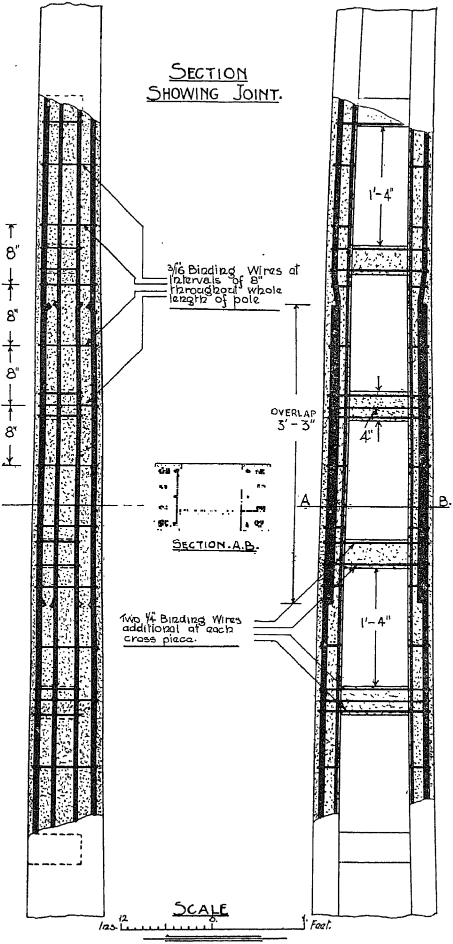


FIG. 78.—Ferro-concrete pole.
Overlapping joints in the reinforcement are shown to introduce the calculations involved, but welded joints would invariably be used in modern practice.

steel and the concrete, the failure consists of a very large number of *small* hair cracks extending along the whole length of the pole. Moisture from the air enters these cracks and automatically seals them by acting on minute unhydrated particles of cement. Thus the steel rods are protected from corrosion.

STRENGTH OF JOINT (Fig. 78).

Length of Joint = 39 ins.
Centre of Joint = (39 — 19·5 — 2)12 = 210 inches from point of loading

MAXIMUM BENDING MOMENT AT CENTRE OF JOINT

$$= 515\,000 \times \frac{210}{366} = 296\,000 \text{ lb.-ins.}$$

$$\text{Arm of couple} = 11 \text{ inches approx.}$$

$$\therefore \textit{Tensile load on joint} = \frac{296\,000}{11} = 26\,900 \text{ lb.}$$

$$\textit{Surface area of reinforcing rods} = 39 \times \pi \left(\tfrac{3}{4} + \tfrac{3}{4} + \tfrac{7}{16} + \tfrac{7}{16}\right) = 292 \text{ sq. ins.}$$

$\therefore$ *Max. longitudinal stress between steel and concrete*

$$= \frac{26\,900}{292} = 92 \text{ lb.} / \text{sq. in.}$$

The safe maximum = 100 lb. / sq. in.

CHAPTER IX.

ANGLES AND TERMINALS.

Angles.—We will calculate the stress in the stay wire, etc., making the following assumptions :—

(1) Three ·05 sq. in. copper conductors and an earth wire arranged as in Fig. 26, p. 45.

(2) 34 foot / $11\frac{1}{4}$ inch pole buried 6 feet.

(3) Span length, 250 feet.

(4) Angular deviation, 10 degrees.

Under these conditions the lateral load on each insulator

$$= P + 2 \,.\, T \sin\frac{\theta}{2} \ (p.\ 60)$$

$$= 177{\cdot}5 + 1\,457 \times {\cdot}174 = \underline{431 \text{ lb.}}$$

The total load due to four wires $= 431 \times 4 = 1\,724$ lb.
The centre of pressure is approximately $336 - 28{\cdot}75 = 307{\cdot}25$ inches from ground level.

The bending moment on the pole at the ground level due to wind pressure on the pole itself $= 31\,600$ lb.-ins., which is equivalent to a load of $\frac{31\,600}{307{\cdot}25} = 103$ lb. at a height of 307·25 inches.

(The wind load on the pole fittings is small and may be neglected.)
The total LATERAL LOAD is therefore

$$P = 1\,724 + 103 = 1827 \text{ lb.}$$

Stay (Fig. 79, p. 164).—In order to keep the stay wire well clear from the line conductors it will be advisable to fix it a little below the centre of pressure, say 36 inches from top of pole.

It will not usually be necessary to bother about any small difference between the centre of pressure and the point of attachment of the stay, but we will allow for it in this case to illustrate the principles involved.

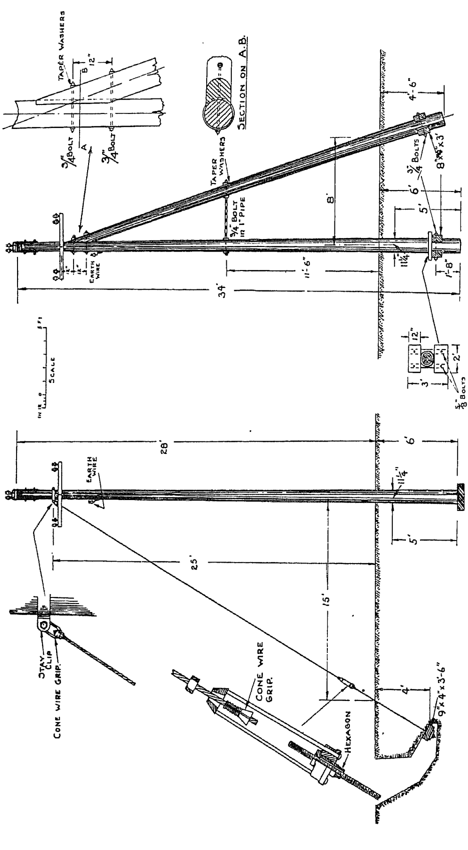


FIG. 79.

FIG. 80.

Arrangements of stay and strut high voltage line. Four ·05 sq. inch copper conductors, 10 deg. angle, 250 feet span.

If P_1 is the horizontal component of the reaction due to the stay wire it must have such a value as to prevent any deflection of the pole at the point of attachment.

It must be emphasised here that as far as the load on the stay is concerned no allowance can be made for the strength of the pole itself, which acts simply as a strut. The pole deflects when stressed due to lateral loading and if this occurs it means that the stay wire or its anchorage has failed.

It can be shown that to prevent any deflection of the pole, P_1 must be equal to $\left(\frac{3H}{2S} - \frac{1}{2}\right)P$, in which H is the height of pole to centre of pressure and S the height of pole to point of attachment of stay. In our example

$$P_1 = \left(\frac{3 \times 307 \cdot 25}{2 \times 300} - \frac{1}{2}\right)P = 1 \cdot 04P$$
$$= 1 \cdot 04 \times 1\ 827 = 1\ 900 \text{ lb.}$$

Now whether we use a stay or a strut, the further from the pole we are able to fix it the less the loads to be dealt with.

We will assume for purposes of calculation that 15 feet spacing is available. Then the

$$\text{Tension in Stay} = \frac{\sqrt{25^2 + 15^2}}{15} \times 1\ 900$$
$$= \frac{29 \cdot 2}{15} \times 1\ 900 = 3\ 700 \text{ lb.}$$

Referring to Table XVI., p. 170, we find that a 7/·16 stay wire will meet the requirements.

$$\text{Compressive Load on Pole} = \frac{25}{15} \times 1\ 900 = 3\ 170 \text{ lb.},$$

to which must be added the dead weight of the conductors, pole fittings and of the pole itself, which would be about 1 850 lb., making a total of 3 170 + 1 850 = 5 020 lb.

The buckling strength can be checked as explained later for terminal poles (see p. 172).

Intensity of Ground Pressure under Butt.—Taking the butt diameter as 12 inches this

$$= \frac{5\ 020 \times 4}{\pi \times 12^2} = 44 \cdot 5 \text{ lb. / sq. in.},$$

which is just below the safe maximum (see Fig. 91, p. 181) at a depth of 6 feet. But as it is most important to avoid settlement it will be advisable to distribute this load over an area of at least 2 sq. ft. by means of a block of concrete or creosoted timber.

The stay wire makes an angle of $\tan^{-1}\dfrac{25}{15} = 59°$ with ground level, so if the stay block is buried 4 feet, an area of $\dfrac{3\,700}{1\,600} = 2{\cdot}31$ sq. ft. is necessary (see Fig. 91, p. 181).

A stay block 9 inches × 4 inches × 3 feet 6 inches long is suggested.

Strut (Fig. 80, p. 164) shows the usual form of construction.

Struts are seldom used. They are rather unsightly and more expensive than stays and in the survey of the route every endeavour should be made to render struts unnecessary. They may sometimes be advisable, however, if stays are likely to be attacked by impurities in the atmosphere, especially near chemical works.

In this connection it may be noted that a galvanised high purity iron stay wire has recently been standardised which is more durable than galvanised steel wire. (See B.S. Specification 183—1927.)

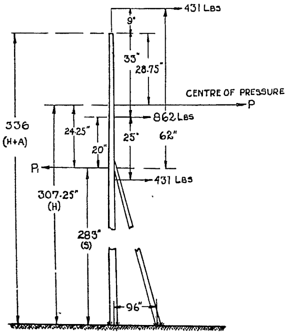


FIG. 81.

Taking the same conditions as assumed above for the stay, we will suppose the strut to be fixed 12 inches below arm bolt.

Bending Moment on Pole at Weakest Section.—This will be where the strut is attached (Fig. 81)

$$= 862 \times 20 + 431 \times 62 = 44\,000 \text{ lb.-ins.}$$

Diameter of pole at this point would be about 8·5 inches.

∴ Moment of resistance

$$= fZ = \frac{f \cdot \pi D^3}{32} = \frac{7\,800 \times \pi \times 8{\cdot}5^3}{32} = 470\,000 \text{ lb.-ins.}$$

There is therefore ample strength here. The horizontal reactio due to strut must

$$= P_1 \left(\frac{3H}{2S} - \tfrac{1}{2}\right) P = \left(\frac{3 \times 307{\cdot}25}{2 \times 283} - \tfrac{1}{2}\right) 1827$$
$$= 1{\cdot}13 \times 1\,827 = 2\,060 \text{ lb.},$$

neglecting wind pressure on strut itself.

Assuming strut to be fixed in ground 8 feet from pole, the upwar pull on pole

$$= 2\,060 \times \frac{283}{96} = 6\,070 \text{ lb.}$$

Allowing for dead weight of pole, etc., the NETT UPWARD PUL ON POLE FOUNDATION

$$= 6\,070 - 1\,850 = 4\,220 \text{ lb.}$$

Cross blocks will, therefore, be necessary to HOLD THE POL DOWN. If they are fixed 4 feet below ground level their are must not be less than $\frac{4\,220}{1\,250} = 3{\cdot}38$ sq. ft. (see Fig. 91, p. 181).

A suggested arrangement is shown in Fig. 80 employing tw 8 inch × 4 inch × 3 feet cross blocks and two 2 inch × 12 inch > 2 feet kicking blocks.

The upward pull on strutted poles is a good deal greater than i usually supposed.

Compressive Load on Strut.

$$\text{This} \quad = 2\,060 \times \frac{\sqrt{96^2 + 283^2}}{96} = 2\,060 \times \frac{299}{96} = 6\,420 \text{ lb.}$$

Assuming the strut to have one end fixed and the other pivote and neglecting the restraint due to the buried portion and to th tie bolt, the *mean* diameter required will be given by the equation

$$B = \frac{2{\cdot}25\pi^2 EI}{L^2} = \frac{2{\cdot}25 \times \pi^2 \times 1{\cdot}2 \times 10^6 \times \pi \times D^4}{64 \times 29{\cdot}5^2 \times 12^2} = 6\,420 \times 3{\cdot}$$

$$\text{Whence } D = \sqrt[4]{\frac{6\,420 \times 3{\cdot}5 \times 64 \times 29{\cdot}5^2 \times 12^2}{2{\cdot}25 \times \pi^3 \times 1{\cdot}2 \times 10^6}} = 7{\cdot}0 \text{ inches.}$$

Length of strut required is about 30 feet, allowing a buried depth of 4 feet 6 inches. A 30 foot / $8\frac{3}{4}$ inch pole is suitable.

Ground Pressure under Butt of Strut.—The strut itself weighs about 550 lb., and assuming for simplicity that the whole of this acts in the direction of the strut the total load on the ground under the strut $= 6\,420 + 550 = 6\,970$ lb.

The symmetrical ground pressure at a depth of $4\frac{1}{2}$ feet must not exceed

$$\frac{4\,740}{144} = 32{\cdot}9 \text{ lb.} / \text{sq. in. (Fig. 91 p. 181).}$$

Area of pole butt $= \dfrac{\pi \times 9{\cdot}35^2}{4} = 69$ sq. ins. approx., therefore the ground under pole will only support $32{\cdot}9 \times 69 = 2\,260$ lb. Consequently cross blocks must be provided to take a load of $6\,970 - 2\,260 = 4\,710$ lb. A creosoted wood or concrete block about 18 inches square, under the butt, would meet the case, but it is preferable to fix a cross block, as the strut is then well anchored and will act as a stay as well, should circumstances ever require it to do so.

If the cross blocks are fixed with their under surface an average of 3 feet 6 inches below ground level, an area of $\dfrac{4\,710}{2\,860} = 1{\cdot}65$ sq. ft. will be necessary.

Two 8 inch $\times$ 4 inch $\times$ 3 foot blocks are suggested.

Strength of Scarf Joint.—The length of scarf on the strut will be about 2 feet and it is therefore advisable to use two bolts, one at bottom end of scarf and the other about 12 inches above. The vertical load taken by the scarf joint $= 6\,070$ lb.

If the strength of the joint so constructed is checked as shown on page 122 it will be found to be distinctly weak, depending as it does simply on two bolts, and the help given by friction.

The moment of resistance of the pole itself can only come into play if the strut foundations give, and this is forbidden by the regulations.

The fact that this type of joint seldom fails can only be ascribed to the rare occurrence of the hypothetical loading conditions.

To make a really satisfactory job and provide a factor of safety of 3·5 an oak block should be fitted as in the case of an "A" pole, or the strut should be let into the pole for an inch or so at the top.

The pole invariably has sufficient margin of strength to permit o this.

Use of Rutter Poles at Angles.—Ref. to Fig. 65, page 132 shows than an 8-inch Rutter pole has a safe working load of about 2 400 lb. at a point 26 feet from ground level and would therefore be quite suitable for the conditions considered above, thus obviating the use of stay or strut.

Rutter poles are now being largely employed for angles, and they are particularly useful in cases where space is limited.

In all cases angle (and terminal) poles should be given a slight "rake," *i.e.* an inclination away from the pull to allow for the small "give" in the foundations which occurs in the initial stages when the load is applied.

Terminals.—We can seldom use cap fittings on terminal poles, and it is advisable to allow greater clearances between conductors, therefore somewhat higher poles will be required if the triangular arrangement is maintained. To obviate the use of longer poles the three conductors can be placed in the same horizontal plane, but this does not make such a neat job. We will base our calculations on a 36 foot / $11\frac{1}{2}$ inch pole buried 6 feet, the stay wire being fixed 26 feet from ground level and the conductors arranged as shown in Fig. 26, page 45.

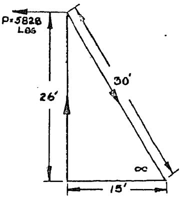


Fig. 82.

The maximum longitudinal pull on the pole under basic loading conditions $= 1\,457 \times 4 = 5\,828$ lb.

If the stay is fixed in the ground 15 feet from foot of pole, the Tension in Stay Wires (Fig. 82)

$$= T = \frac{5\,828\sqrt{26^2 + 15^2}}{15} = 11\,660 \text{ lb.},$$

and the Compressive Load on Pole

$$= 5\,828 \times \frac{26}{15} = 10\,110 \text{ lb.},$$

to which must be added the weight of pole, pole ironwork and of half a span of ice-loaded conductors and earth wire. This will approach 1 500 lb.

Therefore Total Compressive Load on Pole

$$= 10\,110 + 1\,500 = 11\,610 \text{ lb. approx.}$$

To provide the required factor of safety of 2·5, the breaking load of stay wires must not be less than 11 660 × 2·5 = 29 150 lb. Table XVI. gives particulars of the most common sizes of stay wire.

Table XVI.—*Particulars of Stay Wires and Stay Rods.*

		Breaking Load, lb.	Safe Working Load, lb.	Weight per Foot, lb.	
Galvanised Steel Stay Wire	7 / ·08	2 450	980	·120	B.S. Spec. 183, 1927.
,, ,, ,,	4 / ·16	5 600	2 240	·274	
,, ,, ,,	7 / ·16	9 800	3 920	·479	
,, ,, ,,	19 / ·16	26 600	10 640	1·310	
Stay Rods with Tighteners	$\frac{5}{8}$ in.	10 650	4 260	—	British P.O. Standard.
,, ,, ,,	$\frac{3}{4}$,,	15 900	6 360	—	
,, ,, ,,	$\frac{7}{8}$,,	21 000	8 400	—	
,, ,, ,,	1 ,,	29 100	11 640	—	

The figures in the table assume a breaking stress of 70 000 lb. / sq. in. for the galvanised steel stay wire and about 52 000 lb. / sq. in. for the galvanised wrought iron stay rods (at bottom of threads). It is not advisable to use wire of greater tensile strength, as it deteriorates more rapidly.

Instructions for Attaching 7-Strand 0·16 Dia. Stay Wire to Thimble.—Bend the stay wire to form two knees 7 inches apart, the first of these knees being 23 inches from the end of the wire.

Bend the wire between the two knees round the thimble, using the stay tool to draw it close into the groove. Unstrand the free end, straighten out the wires, pick out one end for the first lap, and loosen the tool whilst the wire is passed underneath it, again grasp the remaining wires with the tool and place them symmetrically parallel with and around the main strand, so that they will bind into it without spoiling its circular shape. Grip with the tool and revolve the latter with the free wire under the hook on the thimble side of the tool. This wire should make eight laps.

Treat the other wires the same way, as shown in Fig. 83.

The projecting short ends of each wire (which should not be more than $\frac{1}{2}$ inch long) must be worked in by grasping the splice with the

tool (the ends being within the hollow of the tool) and turning th tool over each end until it is worked in.

Method of Attaching 7-Strand 0·16 Stay Wire to Pole.— Lap twice round the pole, secure by half a dozen No. 4 S.W.G staples and finish off the loose end on to the standing part in th

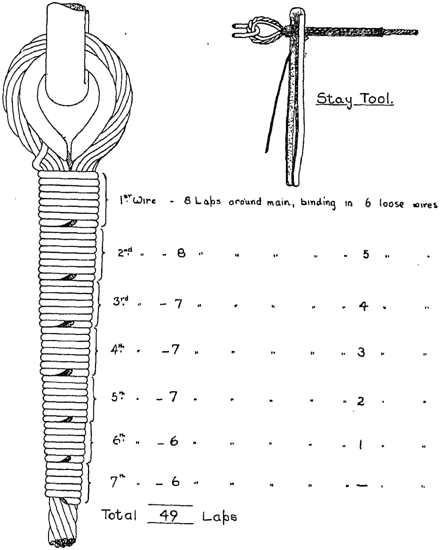


Fig. 83.—Making off 7-strand ·16 inch dia. stay wire on thimble.

manner described above. Alternative methods are shown in Fi 79, p. 164.

For a breaking load of 29 150 lb. it will be seen that three 7/· stay wires are required, or their equivalent.

(For symmetry, using an H. Pole, four 7/·16 stay wires wou probably be used in this case.)

If, however, a distance of 26 feet from the foot of the pole is available, the load on the stay will be reduced to

$$\frac{5\,828\sqrt{26^2 + 26^2}}{26} = 8\,240 \text{ lb.}$$

In this case three 7/·16 stay wires will give a F. of S. of $\frac{3 \times 9\,800}{8\,240} = 3{\cdot}56$, and two such wires a F. of S. of 2·37 only, which is hardly sufficient, but in practice they might possibly be made to satisfy the requirements by fixing them a little further from the pole.

The direct compressive loading on the pole will in this case be reduced to

$$5\,828 + 1\,500 = 7\,328 \text{ lb.}$$

The effects of this compressive loading will now be considered.

Resistance of Earth under Pole to Direct Compression.—The intensity of pressure on the earth under the pole when the stay is 15 feet from pole

$$= \frac{11\,610}{\frac{\pi(12)^2}{4}} = 103 \text{ lb.} / \text{sq. in. approx.}$$

From Fig. 91, page 181, it will be seen that the maximum safe intensity of pressure at a depth of 6 feet is about 58 lb. / sq. in. It will therefore be necessary to distribute the pressure by means of a block of creosoted wood or concrete.

Strength of Pole to Buckling.—It was pointed out on page 119, when considering the buckling strength of the compression member in "A" poles, that no great precision could be claimed for the calculations. The same remark applies here.

It is difficult to procure poles *perfectly* straight and to erect them *exactly* vertical. The loading is not concentric, and the conductors, earth wire and stays are not all attached to the pole at the same point. Moreover, the "end conditions" and the "effective" length of the pole considered as a strut can only be guessed at.

Lateral deflection of the pole in strong winds further complicates the problem, but this can be obviated by splaying out two of the terminal stays as indicated in Fig. 84.

It will be realised, therefore, that exact calculations are impossible, taking all the relevant factors into consideration, but Euler's

formula for a strut *hinged* at *both ends*, taking values for E, J and L as defined below will be found to give results agreeing closely with experiment.

If $E =$ Modulus of elasticity $= 1{\cdot}2 \times 10^6$ lb. / sq. in.,

$J =$ Moment of inertia (in inch units) of the cross-section of the pole about half way up,

$L =$ Overall length of pole up to point of loading (in inches) (the reaction of the ground to the buried portion being neglected),

$B =$ BUCKLING LOAD IN POUNDS,

then
$$B = \frac{\pi^2 . E . J}{L^2}.$$

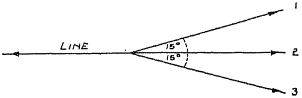


FIG. 84.

In our example

$$\text{Mean diameter of pole} = \frac{8{\cdot}5 + 11{\cdot}5}{2} = 10 \text{ inches approx.}$$

$$\therefore J = \frac{\pi D^4}{64} = \frac{\pi . 10^4}{64} = 491 \text{ inch units.}$$

$$L = (36 - 4)12 = 384 \text{ inches.}$$

$$\therefore B = \frac{\pi^2 E . J}{L^2} = \frac{\pi^2 \times 1{\cdot}2 \times 10^6 \times 491}{384^2} = 39\,400 \text{ lb.}$$

(*a*) *With stays fixed* 15 *feet from pole*

$$\text{F. of S.} = \frac{39\,400}{11\,610} = 3{\cdot}39.$$

(*b*) *With stays fixed* 26 *feet from pole*

$$\text{F. of S.} = \frac{39\,400}{7\,328} = 5{\cdot}38.$$

The pole selected would, therefore, be quite suitable for case (*b*), but is not quite strong enough for case (*a*).

It is to be remarked, however, that the minimum specified diameter of the standard pole has been assumed. A consignment will

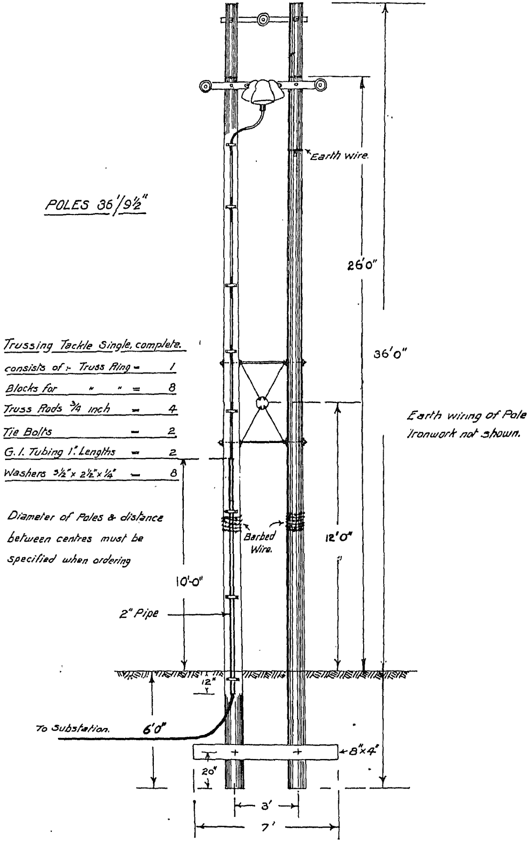


Fig. 85.—Typical terminal "H" pole. (For details of pole fittings, see Fig. 86.)

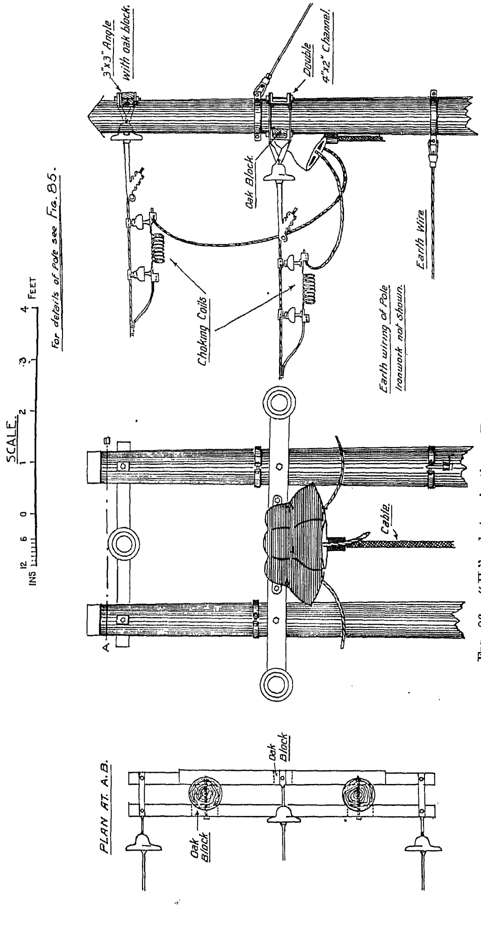


FIG. 86.—"H" pole termination. (For details of pole, see Fig. 85.)

invariably include some poles with diameters appreciably above the minimum and these would naturally be earmarked for terminals and angles.

In practice, waylcave considerations tend to shorten up the stays and it may be found necessary to use non-standard single poles of large diameter or, preferably, "H" poles.

The latter are more desirable from electrical considerations as the greater space available makes it more convenient for dealing with conductors and stay wires and for fixing cable terminating boxes, switchgear, etc.

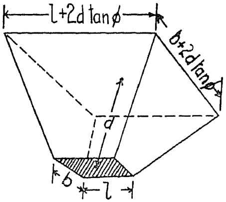


Fig. 87.

Figs. 85 and 86, pages 174 and 175, show a suitable design for the line under consideration.

Stay Anchorages.—It is often assumed that the resistance offered to a stay block is equal to the weight of earth contained in the frustrum of a pyramid of which the smaller base is the stay block itself (assumed horizontal) the side faces make an angle ϕ with the vertical and the larger base is the ground surface.

The weight of such a frustrum of earth (Fig. 87) is given by the following expression :—

$$W = \tfrac{1}{3}wd\{(l + 2d\tan\phi)(b + 2d\tan\phi) + lb + \sqrt{lb(l + 2d\tan\phi)(b + 2d\tan\phi)}\}$$

in which $d =$ depth buried, $l =$ length, and $b =$ breadth of block, $\phi =$ angle of repose of soil and $w =$ weight of soil per unit volume.

This rule does not appear to have a theoretical basis of any sort and the fact that it gives reliable results in practice (if b is not less than (say) 8 inches) is undoubtedly due to the neglect of two other factors, *viz.* the Cohesion of the soil and the Inclination of the Pull.

Consider a vertical retaining wall AB (Fig. 88) with horizontal ground surface AC. It can be shown that if the wall is moved horizontally towards the soil it retains, rupture takes place along the line BC, making an angle of $\left(45 + \frac{\phi}{2}\right)$ with the vertical.

When a stay block is placed at B in the usual way so as to bear on undercut soil, the cohesion of the soil to the left of the vertical AB is destroyed at least temporarily and may therefore be neglected.

If it be conceded that the line of rupture when the anchorage fails may possibly be the line BC as defined above, then the *vertical rupture intensity* of the soil at the depth d will be due to the reaction of the triangular mass of soil ABC. This reaction will be proportional to the weight of the mass, together with the cohesive force tending to prevent separation along the line of rupture. Anything like a complete expression for this reaction would be too cumbersome for practical use and, moreover, owing to the want of homogeneity of the soil and the uncertainty of the values of the specific weight, angle of repose, etc., it is fatuous to attempt close accuracy.

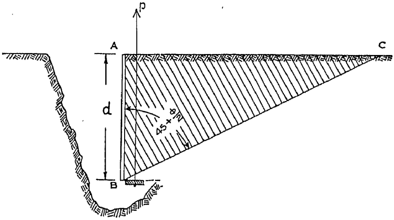


FIG. 88.

Suppose the stay block to be one foot wide, that the surface is horizontal and the pull vertical. The weight of the volume of soil of triangular section ABC and one foot in thickness, which contributes to hold down one foot length of the block

$$= W = \tfrac{1}{2}\, wd^2 \tan\left(45 + \frac{\phi}{2}\right) \text{ lb.}$$

in which $w =$ weight of soil per cubic foot in pounds.
$d =$ depth in feet.
$\phi =$ angle of repose.

Now the cohesive force can be shown to be a function of the *height which the soil will stand when freshly cut,* and also of the angle of repose, but to simplify matters we will assume that the effect of cohesion is apparently to increase the specific weight of the soil.

With the above assumptions, therefore, the vertical intensity of

pressure on the stay block when the anchorage is on the point of giving way may be written

$$p = Kwd^2h \tan\left(45 + \frac{\phi}{2}\right) \text{ lb. / sq. ft.}$$

h being the height in feet which the soil will stand when freshly cut and K some constant yet to be determined.

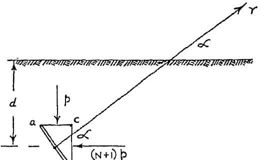


FIG. 89.

Now consider the state of affairs when, as is usual, the pull is not vertical.

Let ab (Fig. 89) represent section of stay block of unit area, the inclination of the pull being $\propto°$ with the ground surface.

Assume the ratio of the horizontal rupture intensity of the soil to the vertical rupture intensity to be $(N + 1)$. Then if r equals the pull on the block at which it gives, we have

$$\begin{aligned} r \,.\, ab &= p \,.\, ac \,.\, \sin \propto + (N + 1) \,.\, p \,.\, bc \,.\, \cos \propto \\ &= p\{\sin^2 \propto + (N + 1) \cos^2 \propto\} \\ &= p\{1 + N \cos^2 \propto\} = p\{1 + N(1 - \sin^2 \propto)\}. \end{aligned}$$

Substituting the value for p found above we get

$$r = Kwd^2h \tan\left(45 + \frac{\phi}{2}\right)\{1 + N(1 - \sin^2 \propto)\} \text{ lb. / sq. ft.}$$

It is realised that the above reasoning is open to criticism in many respects, but it is interesting to compare it with the following very similar formula given in a paper in the *Journal of the Institution of Civil Engineers*, in 1912, by Capt. (now Lt. Col.) C. E. P. Sankey R.E. ret. :—

$$r = Kwd^2h \sin 2\phi\{1 + N(1 - \sin \propto)\} \text{ lb. / sq. ft.}$$

It will be found that, providing suitable constants are chosen the results obtained with one formula are not very different from those obtained with the other.

In the paper referred to, the experimentally determined value for the constants K and N to suit the latter formula were given a 0·49 and 2·37 respectively, but admitting the difficulty of assignin

precise values to w, h and ϕ, the following simplified expression was suggested as being quite close enough for practical purposes. As it has proved reliable for many years, its use is recommended.

$$r = wd^2h \sin 2\phi(1{\cdot}5 - \sin \propto) \text{ lb./sq. ft.}$$

Although based on consideration of a block 1 foot broad, experiments show that the expression can be used for any breadth up to several feet.

It has also been verified that the effective breadth of a round log is equal to its diameter.

The holding power is reduced if the soil becomes wet. This can be allowed for by reducing the value of h.

Approximate values of the constants for various soils are given in Table XVII.

TABLE XVII.—*Constants for Various Soils.*

	w, lb.	h, feet.	ϕ, degrees.
Mud	90	—	—
Loose dry earth (loamy soil)	90	0–1	25
Ordinary surface earth (loamy soil)	90	1–3	25
Well-drained earth (loamy soil)	100	5–10	30
Moist earth (loamy soil)	100	1–3	40
Very wet earth (loamy soil)	100	0–1	15
Ordinary dry clay	120	9–12	30–35
Damp clay, well drained	120	4–8	45
Wet clay	120	0–3	15–20
Clean dry sand	100	0–1	30–35
Wet sand	100	1–5	25–30
Clean gravel	110	0–1	40–45
Damp shingle	100	—	40
Loam, with gravel	110	1–3	25
Sand, with gravel	110	0–1	25
Clay, with gravel	110	1–3	30–40

For well drained, loamy soil we may take as conservative values $w = 90$, $h = 5$ and $\phi = 30°$. Substituting these values in the formula and allowing a factor of safety of 2·5 as required by the E.C. Regulations, we get

$$r = 156d^2(1{\cdot}5 - \sin \propto) \text{ lb./sq. ft.}$$

Values of r for various depths and angles are plotted in Fig. 91.

In our example we will for simplicity deal with one stay anchorage only, assuming that it takes one-third of the load.

It is advisable to have in all cases at least two distinct stays and anchorages, separated by not less than 6 feet.

Case (1) Stay 15 feet from pole, $T = \frac{11\,660}{3} = 3\,890$ lb., $\propto = 60°$.

Case (2) Stay 26 feet from pole, $T = \frac{8\,240}{3} = 2\,750$ lb., $\propto = 45°$.

Assuming a depth of 5 feet, we find by reference to Fig. 91 that the safe working load per square foot equals 3 100 lb. at 45° and 2 500 lb. at 60°. Therefore the area of stay block required

$$\text{Case (1)} \quad = \frac{3\,890}{2\,500} = 1{\cdot}56 \text{ sq. ft.}$$

$$\text{Case (2)} \quad = \frac{2\,750}{3\,100} = 0{\cdot}89 \text{ sq. ft.}$$

Theoretically, if the stay block is 9 inches wide it need not be longer than 2·08 feet in case (1) and 1·19 feet in case (2).

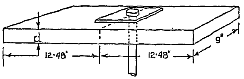


FIG. 90.

Now consider the strength of the block itself.

Strength of Stay Block (Fig. 90).—With a load of 3 890 lb. and a stay block 2·08 feet by 9 inches, what should be its thickness?

First consider bending:—

$$\textit{Distributed load per inch length} = \frac{3\,890}{24{\cdot}96} = 156 \text{ lb.}$$

$$\textit{Maximum B.M.} \text{ (at centre)} = \frac{wl^2}{2} = \frac{156 \,.\, 12 \,.\, 48^2}{2} = 12\,150 \text{ lb.-ins.}$$

$$\text{Moment of resistance of section of block} = M = fZ = f \,.\, \frac{bd^9}{6}$$

$$= 7\,800 \,.\, \frac{9 \,.\, d^2}{6} \text{ lb.-ins.}$$

Allowing a factor of safety of 3·5

$$d^2 = \frac{12\,150 \,.\, 3{\cdot}5 \,.\, 6}{7\,800 \,.\, 9} = 3{\cdot}64$$

whence $d = 1{\cdot}91$ inches minimum.

$$\textit{Maximum shear stress} = \frac{3\,890}{9 \times 1{\cdot}91 \times 2} = 113 \text{ lb.} / \text{sq. in.}$$

This is not excessive.

An iron washer 6 inches $\times$ 6 inches $\times$ $\frac{1}{4}$ inch should always be used under the head of the stay bolt, to distribute the pressure. This washer is neglected in the above calculations and the values are therefore on the safe side.

A stay block 24 inches $\times$ 9 inches $\times$ 2 inches thick will obviously satisfy requirements, but as the cost of the stay blocks is a very small percentage of the overall cost of the line there is no need to cut the

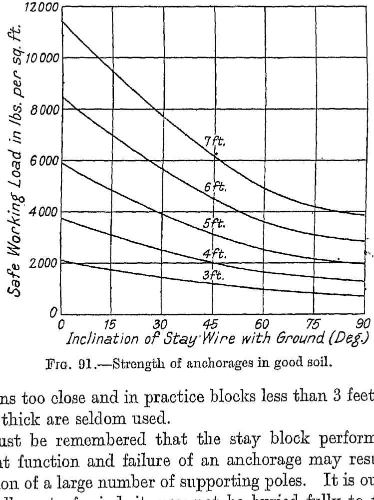


FIG. 91.—Strength of anchorages in good soil.

dimensions too close and in practice blocks less than 3 feet long and 4 inches thick are seldom used.

It must be remembered that the stay block performs a very important function and failure of an anchorage may result in the destruction of a large number of supporting poles. It is out of sight and usually out of mind, it may not be buried fully to the depth prescribed, it may be damaged a little when fixing, the creosoting may be imperfect, and the rate of decay more rapid than anticipated, and, moreover, we can seldom fix precise values for h and ϕ.

In conclusion, the use of thin sheet-iron stay plates may be referred to briefly.

Theoretically, the uniformly distributed breaking load o iron plate 24 inches square, if assumed to be supported at the ce only by a 6 inch × 6 inch washer under the bolt head, is a 5 000 lb. for a plate $\frac{3}{16}$ inch thick and 9 000 lb. for a plate $\frac{1}{4}$ thick.

Actually plates will support greater loads than these, since bending which occurs causes a redistribution of the load as i creases, with a maximum value at the centre, and further, in initial stages, the reaction of the earth below the plates opp the tendency to bend.

Experimentally, a plate 24 inches × 24 inches × $\frac{3}{16}$ inch found to stand up to 14 000 to 16 000 lb. temporarily and gav 9 000 to 11 000 lb. when sustained. Figures for a 24 inch > inch × $\frac{1}{4}$ inch plate are 20 000 and 15 000 approximately.

It may be inferred from this that the safe maximum wor load for a 24 inch × 24 inch plate is $\frac{10\,000}{2{\cdot}5} = 4\,000$ lb. when $\frac{3}{16}$ thick and $\frac{15\,000}{2{\cdot}5} = 6\,000$ lb. when $\frac{1}{4}$ inch thick.

To take full advantage of the bearing surface and use the va given in Fig. 91, it will clearly be necessary to reinforce the pl radially.

CHAPTER X.

CONDUCTORS OTHER THAN COPPER.

CONSIDERATION of other conductor materials has been purposely postponed, because comparison between the various more or less suitable materials is very much influenced by their mechanical properties as well as their electrical.

The main desiderata in a conductor material are :—

1. Low price.
2. High specific electrical conductivity.
3. High tensile strength.
4. Chemical inertness to atmospheric effects.
5. Ease of erection and jointing.

Particulars of various conductor materials are given in Table XVIII.

Pure hard-drawn copper most closely satisfies all the required conditions. It is still the best known and most widely used material and at its present price it is likely to remain so both for low voltage and high voltage distribution. It lasts indefinitely in use under ordinary atmospheric conditions and it has a high scrap value.

Copper Alloys.—Owing, however, to the large ratio of sag to span length necessary with the smaller copper wires for high voltage lines, a conductor of greater tensile strength is desirable for the transmission of small amounts of power.

Bronze.—The addition of a little tin and silicon to copper produces an alloy known as " bronze " which has a much greater tensile strength than copper, but unfortunately the gain in strength is only obtained at the expense of a reduction in conductivity. The standard P.O. silicon bronze (B.S. Spec. 175—1923) has a tensile strength of about 100 000 lb. / sq. in., which is a 70 % increase on that of H.D. copper, but its conductivity is reduced by more than 100 %. For equal conductivity it costs more than twice as much as pure copper.

TABLE XVIII.—*Particulars of Overhead Line Conductors.*

	H.D. Copper, B.S.S. 125.	P.O. Standard Bronze, B.S.S. 175.	Copper Clad Steel, 40 %.	Copper Clad Steel, 30 %.	Cadmium Copper Alloy, 93 %.	Cadmium Copper Alloy, 84 %.	H.D. Aluminium, B.S.S. 215.	Steel Cored Alumin, B.S.S. 215.	Galvanised Steel. P.O. Std. Line Wire, B.S.S. 182, ·08 % Carbon.	Galvanised Steel. P.O. Std. Stay Wire, B.S.S. 183, ·2 % Carbon.	Galvanised Steel. 45 Ton Quality.	Galvanised Steel. 80 Ton Quality.
Breaking stress (average), lb. / sq. in.	60 000	100 000	80 000	80 000	73 000	81 000	26 000	45 000	52 000	70 000	100 000	180 000
Working stress (average), lb. / sq. in. Max. by E.C. Regns.	30 000	50 000	40 000	40 000	36 500	40 500	13 000	22 500	26 000	35 000	50 000	90 000
Modulus of elasticity, lb. / sq. in.	18×10^6	17×10^6	20×10^6	20×10^6	18×10^6	18×10^6	$9{\cdot}6 \times 10^6$	$12–13{\cdot}5 \times 10^6$	30×10^6	30×10^6	30×10^6	30×10^6
Coefficient of linear expansion per °F.	$9{\cdot}222 \times 10^{-6}$	10×10^{-6}	7×10^{-6}	$6{\cdot}8 \times 10^{-6}$	$9{\cdot}225 \times 10^{-6}$	$9{\cdot}225 \times 10^{-6}$	$12{\cdot}6 \times 10^{-6}$	$10–10{\cdot}9 \times 10^{-6}$	$6{\cdot}4 \times 10^{-6}$	$6{\cdot}4 \times 10^{-6}$	$6{\cdot}4 \times 10^{-6}$	$6{\cdot}4 \times 10^{-6}$
Weight per cu. inch (lb.)	·323	·32	·298	·298	·323	·323	·097	·134	·285	·285	·285	·285
Relative resistance	1·0	2·10	2·56	3·41	1·075	1·19	1·64	1·64	7·5	8·5	10·0	12·5
Relative conductivity	1·0	·475	0·39	0·293	·93	·84	0·61	0·61	·133	·118	·10	·08
Weight for equal cond.	1·0	2·1	2·36	3·15	1·075	1·19	0·49	0·68	6·6	7·50	8·85	11·0
Diameter for equal cond.	1·0	1·45	1·60	1·85	1·04	1·09	1·28	1·28	2·74	2·92	3·16	3·54
Tensile load for equal cond.	1·0	3·5	3·40	4·55	1·31	1·60	0·71	1·23	6·50	9·90	16·7	37·5
Cost for equal cond.	1·0	2·70	—	—	1·20	1·30	1·15	1·30	1·50	2·00	2·50	3·25

Spec. resce. of copper = ·685 microhms per inch cube (B.S.S. 125).
Density of copper = 8·89 gm. per c.c. = 555 lb. / cubic foot (B.S.S. 125).
Pure Swedish charcoal iron, well annealed (99·85 % iron) has a breaking stress of about 45 000 lb. / sq. in. and resistance 5·8 times that of

Copper-Cadmium.—A copper-cadmium alloy which has recently been placed on the market seems to be much more promising than bronze, a 35 % increase in strength being secured at the expense of 16 % only in conductivity. For equal conductivity it costs about 30 % more than pure copper (see Table XVIII.).

Copper-Steel.—Since high tensile steel can be obtained with a breaking stress exceeding 200 000 lb. / sq. in. compared with 60 000 lb. / sq. in. for H.D. copper, it is natural that endeavours should have been made to combine the strength of the former with the conductivity of the latter. A method which suggests itself is to lay up an annular layer of copper wire strands around a steel core, but the objection to this is that the galvanising would quickly disappear by electrochemical action as it is in contact with copper. This method is used very largely to reinforce aluminium conductors and will be again referred to later.

In the U.S.A. a copper-clad steel conductor has been used for many years, the copper coating being metallurgically welded on to the steel core, rendering the latter absolutely immune from corrosion.

Aluminium.—The only other metal in competition with copper from a purely electrical point of view is aluminium. At the prices now ruling, aluminium and copper cost about the same for equal conductivity.

It may be said at once, however, that aluminium is not a serious competitor for light overhead lines, owing to the following disadvantages :—

(1) *Lower Tensile Strength.*—This necessitates a larger ratio of sag to span length, which in turn means longer and stronger poles. (As a partial set-off, however, the terminal stresses are not so great.)

(2) *Greater Diameter.*—This increases the lateral wind loading and therefore somewhat stronger supports are required for this reason as well.

(3) *Greater Ratio of Wind Load to Weight of Wire.*—This necessitates greater clearances, as the wires are deflected more from the vertical than copper wires of the same conductivity. This fact often rules out the smaller aluminium wires altogether.

(4) More care is required in erecting and jointing.

(5) Smaller scrap value.

The first three disadvantages can be studied by reference to Tables XIX. and XX.

TABLE XIX.—*Comparison of Aluminium Conductors with Their Copper Equivalents.*

		·02 Copper.			·05 Copper.			·10 Copper.			·20 Copper.		
		Copper.	Alum.	Alum. Steel.	Copper.	Alum.	Alum. Steel.	Copper.	Alum.	Alum. Steel.	Copper.	Alum.	Alum. Steel.
		·162	3 / ·118	No standard equivalent.	3 / ·147	7 / ·122	7 / ·132	7 / ·136	7 / ·173	6 / ·186 7 / ·062	7 / ·193	19 / ·149	30 / ·118 7 / ·118
Resce. per 1 000 yards	R ohms	1·21	1·24		·5	·5	·5	·25	·25	·247	·124	·1222	·1238
Reactance per 1 000 yards	X ohms	·375	·35		·33	·32	·32	·315	·30	·30	·295	·28	·28
Diameter of wire	d ins.	·162	·254		·317	·366	·396	·408	·519	·558	·579	·745	·826
Weight of wire per foot run	w lb.	·0795	·0392		·20	·0976	·1446	·399	·197	·268	·803	·396	·657
Weight of $\frac{3}{8}$ in. ice per ft. run	w_i lb.	·252	·295		·321	·347	·361	·363	·418	·437	·441	·515	·563
Maximum working load	T lb.	633	429		1 457	1 021	2 053	2 935	1 895	3 694	5 635	3 893	10 200
Area of wire	A sq. in.	·02061	·032		·05	·08	·08	·10	·162	·16	·20	·325	·322
Weight of wire + ice	lb.	·331	·334		·521	·445	·506	·762	·615	·705	1·244	·911	1·225
Wind pressure per foot run (8 lb.)	lb.	·605	·669		·710	·744	·764	·771	·846	·872	·885	·996	1·051
Total weather loading at 22° F.	W lb.	·690	·746		·88	·865	·915	1·08	1·047	1·12	1·53	1·35	1·61
Sag for 100 feet span	D feet	1·36	2·18		·755	1·057	·557	·46	·69	·379	·34	·433	·197
62° F. 15 lb. wind, ratio	$\frac{\text{Wind load}}{\text{Weight}}$	2·55	8·09		1·98	4·68	3·42	1·28	3·30	2·60	0·90	2·35	1·57
62° F. 15 lb. wind, ratio of sags for same spans		1·0	1·57		1·0	1·4	·74	1·0	1·51	·82	1·0	1·29	·57
62° F. 15 lb. wind, deflection from vertical		69	83		63	78	74	52	73	69	42	67	57

TABLE XX.—*Illustrating Comparative Cost of Copper and Aluminium Conductors. Erected to 1923 E.C. Regulations ($\frac{1}{2}$ inch ice) H.V. Lines. (Three Conductors and one $\frac{7}{16}$ G.S. Earth Wire.) Conductor arrangement shown in Fig. 28, page 45.*

Material.	Size.	Cross Section (square inches).	Overall Diameter (including ½-in. ice).	Approx. Economic Span Length.	Wind Load.	Sag at 122° F.	Height of Pole to Point of Loading.	Distance of Point of Attachment of Lowest Line Conductor from Top.	Total Height of Pole Out of Ground.	Overall Length of Pole.	Butt Diameter of Pole (from Chart).	Nearest Standard Pole.	Cost per Pole including Distribution of Poles on Site.	Pole Ironwork, Insulators, Dressing and Erection.	Capitalised Value of Wayleaves.	Total Cost per Pole.	No. of Poles per Mile.	Total Cost of Supports per Mile.	% Difference on Supports.	Weight of Each Conductor per Mile.	Cost of Conductors per Mile.	Total Cost per Mile Conductors + Supports.	% Difference on Supports + Conductors.
		Sq.ins.	Ins.	Ft.	Lb.	Ft.	Ft.	Ft.	Ft.	Ft.	Ins.		£	£	£	£	No.	£	%	Lb.	£	£	%
Copper	3/·147	·05	1·317	270	915	6·35	26·35	3·1	29·45	35·4	11·5	36/11½	4·4	2·0	1·5	7·9	19·5	154	—	1057	120	274	—
Alumin.	7/·122	·0817	1·366	200	705	5·35	25·35	2·4	27·75	33·4	10·5	34/11¼	4·1	1·8	1·5	7·4	26·4	195	+25	515	117	312	+13
Steel-cored Alum.	7/·132	·0821	1·396	300	1058	5·40	25·4	3·5	28·9	35·0	11·8	40/12	5·2	2·0	1·5	8·7	18·2	158	+2	611	117	275	—
,,	7/·132	·0821	1·396	250	882	3·34	23·34	2·9	26.24	31·9	10·75	32/11	3·7	1·7	1·5	6·9	21·1	145	—6	611	117	262	—4·5

All other costs are assumed constant.

Steel-Cored Aluminium.—To overcome the first disadvantage of aluminium noted above, steel-cored conductors are used, *i.e.* conductors made up in the usual way with concentric layers of aluminium wires, but in which the central wire or wires are of high tensile steel. The objection to using a steel core in stranded copper conductors, referred to on page 185, does not appear to hold with aluminium. The explanation is said to be found in the tight bedding of the relatively soft aluminium wires around the core, which, combined with the final filling of any small interstices between the outer aluminium wires with oxide, prevents any penetration of moisture inside the conductor. In addition, the fact that zinc and aluminium have a very small electrochemical potential difference undoubtedly has a bearing on the immunity from corrosion.

Such a composite conductor is considerably stronger than the electrically equivalent H.D. copper conductor (see Tables XIX. and XX.), therefore the ratio of sag to span length is smaller. This means that longer spans can be used with steel-cored aluminium than with copper and this is of great importance in the transmission of large amounts of power over long distances at very high pressures, which is outside the scope of this work. It is being used extensively on the 132 000 volt main transmission lines now being erected in this country.

It will be noted in Table XX that steel-cored aluminium shows a saving of 4 to 5 % on the cost of supports and conductors, which means about 2 % on the overall cost of the line. Considering its disadvantages it is not a very attractive proposition for the conditions assumed, but it shows far greater economy in long span work.

For distribution purposes where comparatively short distances are involved, a very appreciable saving in first cost must be realised to outweigh the difficulties due to jointing and branch connections. This opinion is based on experience with aluminium lines in this country in the last fifteen years, during which, compared with copper, it has not shown up very well. The main difficulty experienced has been in maintaining continuity with parallel-groove clamp connections, the contact surfaces of which sooner or later become oxidised, however tightly they are clamped together.

However, the aluminium obtainable to-day is much superior in purity to most of that on which the above opinion is based, and joints undoubtedly give less trouble with purer metal. Also the use

TABLE XXI.—*Particulars of Galvanised Steel Conductors. 45-ton Quality—for High Voltage Lines ($\frac{3}{8}$-inch ice).*

Size of Galvanised Steel Strand.	Copper Section of Equivalent Resistance.	Cross-section.	Overall Diameter.	Resistance per 1 000 yards.	Reactance per 1 000 yards.	Weight per foot run.	Safe Working Stress.	Safe Working Load.	Weight of Ice per foot run ($\frac{3}{8}$ in.).	Weight of Wire + Ice per foot run.	Overall Diameter, Wire + Ice.	Wind Load per foot run.	Total Load per foot run.	Oblique Sag at 22° F. 100 Feet Span.	Critical Temperature.
S.W.G.	Sq. in.	Sq. in.	Ins.	Ohms.	Ohms.	Lb.	Lb. per sq. in.	Lb.	Lb.	Lb.	Ins.	Lb.	Lb.	Ft.	Faht.
7 / ·064	·00225	·0225	·192	11·0	0·71	·078	48 000	1 080	·266	·344	·942	·628	·72	·83	245
7 / ·104	·00594	·0594	·312	4·15	0·62	·206	47 500	2 820	·322	·528	1·062	·708	·88	·39	212
7 / ·16	·01407	·1407	·48	1·75	0·57	·489	47 000	6 600	·40	·889	1·23	·82	1·21	·23	168

NOTE 1. The smallest copper conductor allowed is 0·0201 sq. in. (8 S.W.G.).

NOTE 2. *Resistance.*—Assumed 10 times that of equivalent copper section.

NOTE 3. *Reactance.*—The figures are for 50 cycles, 3 feet spacing. They include both internal and external values. For the relatively small currents for which steel conductors are likely to be used in practice, the *total* reactance is approximately double the external reactance.

NOTE 4. *Working Stress.*—The breaking stress of a ·104 single wire is assumed to be 100 000 lb. / sq. in. Allowing a F. of S. of 2, and taking 95 % of this value to allow for stranding, we get $\frac{100\,000}{2} \times \cdot 95 = 47\,500$ lb. / sq. in. The breaking stress of ·064 is somewhat greater and of ·16 a little less.

TABLE XXII.—*Sags and Tensions. Steel Conductors* (45 *ton Quality*) *for Erection Purposes. High Voltage Lines* ($\frac{3}{8}$*-inch ice*).

Span, feet.	Temperature, Faht.	7/16 S.W.G. (·064).		7/12 S.W.G. (·104).		7/8 S.W.G. (·16).	
		Sag, feet.	Tension, lb.	Sag, feet.	Tension, lb.	Sag, feet.	Tension, lb.
200	122	1·52	257	·78	1 320	·65	3 760
	82	1·04	375	·57	1 810	·51	4 790
	62	·88	400	·50	2 060	·46	5 310
	42	·74	527	·45	2 290	·42	5 820
	22	·64	610	·41	2 510	·38	6 430
	22	*3·32*	*1 080*	*1·56*	*2 820*	*·92*	*6 600*
300	122	5·58	157	1·89	1 230	1·52	3 620
	82	4·85	181	1·44	1 610	1·19	4 620
	62	4·50	195	1·28	1 810	1·07	5 140
	42	4·10	214	1·15	2 020	·98	5 610
	22	3·69	238	1·04	2 400	·90	6 110
	22	*7·47*	*1 080*	*3·51*	*2 820*	*2·07*	*6 600*
400	122	11·40	137	4·05	1 020	2·80	3 500
	82	10·80	144	3·19	1 290	2·24	4 370
	62	10·45	149	2·83	1 460	2·02	4 850
	42	10·08	155	2·52	1 640	1·84	5 310
	22	9·71	160	2·26	1 830	1·68	5 820
	22	*13·28*	*1 080*	*6·24*	*2 820*	*3·68*	*6 600*

Basic loading sags and maximum legal tensions shown in italics.

of "cone" types of connections wherever possible instead of a clamp will reduce the jointing troubles.

Consequently, if there should be an appreciable fall in the price of aluminium compared with that of copper, the above views may have to be modified.

Galvanised Steel.—In the above consideration steel has been used really as a carrier for the conductor, but in cases where the size of copper or copper-alloy conductor required from a purely electrical point of view is too small for mechanical reasons it will be sometimes quite feasible to use galvanised steel as the conductor itself, in spite of its high resistance. The inductance is naturally greater than that of non-magnetic conductors, but for the small currents with which steel is likely to be used the ohmic resistance will

TABLE XXIII.—*Illustrating Economy due to Use of Steel Conductors. (H.V. lines to* 1923 *E.C. Regulations,* $\frac{1}{2}$*-inch ice.) Three Conductors and one* $\frac{7}{16}$ *G.S. Earth Wire. Conductor arrangement shown in Fig,* 28, *page*45.

	Span length.	Sag at 122° F.	Wind Load per Span.	Height of Pole required.	Butt diameter of Pole required.	Nearest Standard Pole.	Price per Pole (including distribution on site).	Cost of Insulators, Pole Ironwork, Dressing and Erection.	Cost of Wayleaves Capitalised.	Total Cost per Pole.	No. of Poles per Mile.	Total Cost per Mile (Poles).	Total Cost per Mile (Conductors).	Cost per Mile ($\frac{7}{16}$ G.S. Earth Wire).	Total Cost per Mile (Supports + Conductors and Earth Wire).
	Ft.	Ft.	Lb.	Ft.	Ins.		£	£	£	£	No.	£	£	£	£
*·136 copper .	150	5·0	460	31·9	9·0	34 / 9¼	2·9	1·7	1·5	6·1	35·2	215	37	5	257
·162 copper .	175	5·0	540	32·5	9·75	40 / 9¾	3·8	1·8	1·5	7·1	30·2	214	53	5	272
7 / 12 steel . .	300	2·47	1025	31·7	11·1	34 / 11¼	4·05	1·8	1·5	7·35	17·6	129	40	5	174
7 / 12 steel . .	400	5·65	1367	36·75	12·75	45 / 13	6·35	2·35	1·5	10·2	13·2	135	40	5	180

* ·136 copper is not permitted by the 1928 E.C. Regulations now in force.
All other charges assumed constant.

usually be the predominating factor (see Table XXI). Skin effect is inappreciable.

But unfortunately the life of steel is comparatively short and its scrap value is negligible. It quickly rusts when exposed to the atmosphere and must therefore be well galvanised for O.H. line work.

The tensile strength of steel increases with the carbon content, but the cost and the specific resistance go up as well; moreover, as the strength increases the steel becomes less ductile and flexible and it rusts more quickly. High tensile steel having a breaking stress of 180 000 to 200 000 lb. / sq. in. is used in the cores of aluminium-steel cables and is reputed to be immune from corrosion (see p. 188). But it is not usual to employ steel of greater strength than 100 000 lb. / sq. in. for O.H. power-line conductors, and this will have a shorter life than the standard wires of lower tensile strength used by the post office for telegraph line conductors and stays (B.S. Specs. 182 and 183—1923). The latter last upwards of 20 years, except in certain manufacturing areas, whereas the former will probably not last 15 years.

Particulars of three sizes of steel conductor are given in Table XXI. and sag and tension values for erection purposes in Table XXII. Table XXIII. illustrates the economy due to the use of these conductors.

CHAPTER XI.

SAFETY PRECAUTIONS.

THE legal regulations on the subject are prescribed by the Electricity Commissioners and the Postmaster-General and they are given in full in Appendices I. to IV.

Provisions to Prevent Danger from

1. LEAKAGE.

A. LOW AND MEDIUM VOLTAGE (Regulations 13).—For pressures to earth above 250 volts D.C. or 125 volts A.C.

(i) METAL POLES.—A continuous earthed wire must be provided, running from pole to pole and connected to all the poles. It must be emphasised that an iron pole does not make a very good earth contact in itself, particularly when, as is frequently the case, it is set in concrete. Hence the danger of touching a pole on which there is a faulty insulator, if a good earth connection is not provided.

(ii) WOOD POLES.—In cases where an earth wire does not form part of the conducting system, all ironwork should be bonded to the earth wire. In cases where there are no earth wires, the ironwork should be bonded together to allow a greater surface for the dissipation of leakage currents. Where the leakage on a line is considerable and the resistance of the earth connections is high, it is possible for the potential of the bonding wires to be raised to a dangerous value. For this reason, if bonding wires or lightning conductors are led down a pole to earth plates it is necessary to insulate the bonding wires to a height of 10 feet from the ground. A covering of creosoted wood casing suffices.

STAY WIRES on wood poles must be considered as

part of the metal work and an insulator must be placed in each stay wire at a height of not less than 10 feet from the ground.

It should be noted that a neutral conductor must be earthed at one point only, *viz.* the generating station or sub-station, and it cannot, therefore, be considered as a continuous earthed wire for purposes of complying with this regulation (but see page 54).

Service Lines.—Special attention is drawn to Regulation 8, which lays down that service lines where accessible must be insulated. To comply with this regulation, all conductors should be covered with durable insulating material within 6 feet of a building. Many fatal accidents have occurred due to neglect of this regulation.

B. High Voltage Lines (Regulation 16).—In the case of H.V. lines the danger from leakage is obviously greater and all metal work other than the conductor must be bonded together and connected with earth in all cases. Tinned copper or galvanised iron bonding wire should be used. The earthing may be carried out by a continuous wire, earthed 4 times per mile, or, alternatively, the continuous wire may be omitted and the metal work effectively earthed at each pole.

The former method is nearly always adopted, since effective earthing is not generally practicable at every pole, and although the continuous wire adds considerably to the cost of the line it affords a measure of protection against atmospheric effects and it is also useful as a support for auxiliary conductors or telephone cables.

The earth connecting wire should be enclosed in creosote wood casing for a distance of 10 feet from ground level.

2. Broken Line Conductor.

A. Low and Medium Voltage.—The possibility of a conductor falling when erected in accordance with the E.C. Regulations must be admitted to be remote, but it has to be considered. E.C. Regulation 13 stipulates the provision of a continuous neutral or other earthed wire

carried from pole to pole and so arranged as to m
contact with a falling conductor.

Most L.V. distribution systems work with eart
neutral conductor, which can fortunately be used a
continuous earthed wire to comply with this regulati

It was formerly the practice to use a so-cal
"split" neutral conductor as illustrated in Figs.
and 34 and fix two cross wires in each span as far
from the pole as the lineman could reach or alter
tively, a single neutral conductor sufficed if a triangu
guard was fitted as shown in Fig. 36.

But providing the neutral conductor is pla
directly below the other conductors, the triangu
guard may now be dispensed with, as in Fig. 35.

When the line conductors are arranged in triangu
fashion as in Fig. 33 and 34 one earthed conductor
now suffice if it is staggered from side to side at e
succeeding support. As stated before, this metho
construction appears to the writer to present difficult
and the vertical arrangement of Figs. 35 and 36 is r
likely to be the most popular.

B. HIGH VOLTAGE.—No special guarding against brol
conductors is required on H.V. lines, except in
neighbourhood of roads, railways, etc., but attent
may be drawn to the following clause in Regulation

"The design and construction of the system of ea
connections shall be such that when contact is m
between a line conductor and metal connected w
earth, the resulting leakage current shall not be
than twice the leakage current required to operate
devices which make the line dead."

This implies that ordinary overload protection
not sensitive enough for H.V. lines unless three c
ditions are satisfied, *viz.*, (i) the neutral of the system
earthed, (ii) suitable guards or earth bars are fit
throughout the line so that a broken conductor
make contact with earth, and (iii) the overload t
act instantaneously (*i.e.* no time lag attachments
permitted).

There are available a number of very sensit

protective devices, with which a line conductor on breaking is made "dead" in a very small fraction of a second, before it has time to reach a person underneath. But although admittedly the best forms of protection, they entail special line construction with auxiliary conductors and the cost is generally prohibitive for minor H.V. distribution lines. For such lines ordinary "leakage" protection will suffice. With earthed neutral at the generating station or transformer station, leakage relays can be relied upon to cut off a line in one-tenth of a second when a leakage current of the order of 5 % of the normal full load current flows, although it may not often be necessary or desirable to set the relays too lightly.

Additional Safety Precautions in the Neighbourhood of Roads, Railway and Canals.

A. L.V. AND M.V. LINES.—The regulations for these lines are framed on the assumption that they will be used in residential areas and therefore always in the neighbourhood of roads, etc., and except for increased clearances from ground no further precautions are laid down.

B. H.V. LINES.

(i) CLEARANCE FROM GROUND.—In ordinary cross country work, the specified ground clearance of 20 feet is measured from the lowest line conductor, but when the line is erected along or across a public road the clearance must be taken from the lowest wire on the pole. This means that the poles must be several feet longer near public roads if earth wires or auxiliary conductors are employed.

(ii) WITHIN 50 FEET OF A ROAD OR CANAL.—The following alternative safety devices are prescribed :—

either (*a*) Duplicate insulators and strap wire ;

or (*b*) Single insulators plus an earthing device.

Ref. (*a*) The duplicate insulators are arranged as shown in Figs. 26 and 32, and a strap wire of H.D. copper of the same size as the conductor, or, alternatively, of phosphor bronze of the same strength connects the second insulator to points on the conductor

as far out from the pole on either side as the lineman can reach, *i.e.* from 3 to 4 feet. This strap wire is intended to prevent the wire from falling to the ground in the event of the line conductor being burnt through at a faulty insulator.

That is to say, it is the insulator primarily which causes the anxiety.

Ref. (*b*) An earthing bar or bow of galvanised iron or copper fixed under each conductor is commonly used as shown in Figs. 32 and 37, but the triangular guard arrangement shown in Fig. 36 for L.V. lines is quite suitable on H.V. lines if the conductors are arranged in a vertical plane. The triangular guard can be secured to the earth wire at points 4 feet from the pole and from this point of view it is really better than an earthing bar, which as generally fitted does not usually extend outwards from the pole for more than 18 inches or 2 feet.

(iii) CROSSING A ROAD, CANAL OR RAILWAY.—The following methods of construction comply with the regulations:

Either (*a*) Duplicate insulators plus duplicate conductors;

or (*b*) Duplicate insulators and strap wire plus earthing device.

It will be noted that the regulations make no reservation as to length of span or angle of crossing. It was formerly the practice to shorten up the span at a road crossing as it was believed that a greater factor of safety could be thereby ensured, but it is now generally agreed that it is not good practice to do this. Of the two alternative methods, the second is by far the better, as it does not add to the line loading in any way. Among the objections to the first method are the necessary stronger poles with additional line stays, and tensioning insulators on the second conductors.

Stranded conductors are preferable to solid ones in the neighbourhood of roads.

With regard to railway crossings, the railway authorities do not accept the E.C. regulations without qualification and they should always be consulted when surveying a route which crosses their permanent lines. They usually require duplicate conductors with the power line at right angles to the rails and span as short as possible.

Post Office Regulations.—In addition to those prescribed by the Electricity Commissioners further regulations laid down by the Postmaster-General must be complied with when power lines are erected in the neighbourhood of signal wires. The P.O. Engineering Department's Memoranda on the subject (T.E. 80 and E. in C. 231) are given in full in Appendices III. and IV., but attention is drawn to the following points.

A. Low and Medium Voltage.

Guard Wires at Crossings.—When practicable the crossing should always be effected with the power conductors above, as being invariably larger wires, erected with a higher factor of safety, they are less likely to fall than the signal wires, and, moreover, it will not be necessary to interrupt the power supply when signal wires are being repaired.

Further, the crossing should preferably be as nearly at right angles as possible, as the requirements are then simpler.

Independent guard wires may be used in all cases, but if the pressure to earth does not exceed 250 A.C. and the signal wires are underneath, it will usually be found more convenient and economical to split the neutral of the power system at the crossing span, cross-lacing every 6 feet as required.

If the signal wires are above, it will be necessary to run an additional earthed wire above the power wires, unless the arrangement shown in Fig. 34 is adopted with split neutral and cross lacing.

The normal specified clearance between guard wires and signal wires is 4 feet, but in special cases a clearance of 2 feet may be accepted.

It will be noted that no guard wires are required when the power conductors are insulated and supported by an earthed bare suspension wire, nor are they required up to 250 volts A.C. if *either* the power conductors *or* the signal wires are insulated with an approved weatherproof covering (see Specification, p. 232).

High Voltage.—The P.O. still prefer (but do not now insist) that either the power wires or the signal wires should be placed underground at crossings.

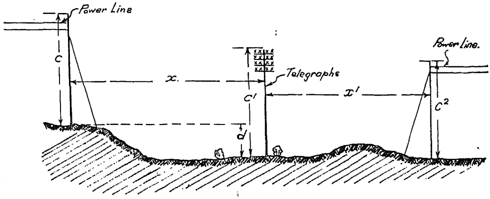
The requirements are roughly indicated in Fig. 92.

In special cases, however, the department has agreed to smaller values of x and x', but this has never been less than $1\frac{1}{2}\,C'$, the height of the signal route, or $1C$, the height of the power circuit route, whichever is the greater. This allows a smaller clearance than the

standard rule in cases where the power wires are higher than the signal wires.

But apart from the question of cost there are important electrical objections to inserting short lengths of cable in either line. This is now more fully realised than formerly and the problem became acute with the advent of 33 000 volt and 66 000 volt transmission.

The latest P.O. regulations, therefore, permit overhead crossings with duplicate conductors plus a cradle guard, which is a compromise



x to be > 1½ (C or C', whichever is the greater) + d (difference of level)

FIG. 92.

that may cost as much as a cable crossing, but is more satisfactory from an electrical point of view.

It may also be noted that consent has been obtained to suspend an armoured cable from a steel wire, which costs much less than putting it underground, because the use of terminal poles and stays is avoided, the line tension being carried through by the suspension wire.

In this connection it may be noted that up to 6 600 volts, wire-armoured, ozone-proof cable is better than lead-covered paper cable, as it is lighter and the cost of sealing boxes is avoided.

APPENDIX I.

ELECTRICITY (SUPPLY) ACTS, 1882 TO 1926. [El. C. 53.]

OVERHEAD LINE REGULATIONS *for securing the Safety of the Public made by the Electricity Commissioners under the Electricity (Supply) Acts,* 1882 *to* 1926.

DEFINITION.

In the following Regulations the expression "line conductors" means conductors used for transmitting a supply of electrical energy, including so much of any service line as may be under the control of the undertakers.

I.—GENERAL.

Material of Line Conductors.

1. Line conductors shall be of copper, aluminium, or such other materials as may be approved by the Electricity Commissioners.

Strength of Line Conductors.

2. All line conductors at the time of erection shall comply, as regards elongation, breaking load and elasticity, with the specification of the British Engineering Standards Association then in force.

Minimum Size of Line Conductor.

3. The minimum permissible size for copper and other line conductors (other than service lines) shall be such as to have an actual breaking load of not less than 1237 pounds, the equivalent minimum cross-sectional area and weight per mile for copper being as follows :—

Conductor.	Cross-sectional area, sq. ins.	Weight per Mile, lbs.
No. 8 S.W.G .	0·0201	409

The minimum permissible size of service line shall be such as to have an actual breaking load of not less than 816 pounds, the equivalent minimum cross-sectional area and weight per mile for copper being as follows :—

Conductor.	Cross-sectional area, sq. ins.	Weight per Mile, lbs.
No. 10 S.W.G.	0·0129	262

Line Conductors to be inaccessible.

4. Line conductors shall be rendered inaccessible to any person from any building or other place without the use of a ladder or other special appliance.

Regard shall be had to the normal use by the occupier of any premises or land and where necessary (*a*) the height of the line conductors shall be increased to provide sufficient clearance for safety in accordance with such use, and (*b*) provision as hereinafter prescribed in Regulations 14 or 17 shall be made to prevent danger.

Line Conductors Crossing other Lines.

5. Where a line conductor crosses over or under, or is in proximity to any other overhead wire, precautions shall be taken by the undertakers to prevent contact, due to breakage or otherwise, between the line conductor and the other overhead wire, or between the other wire and the line conductor.

Provided that this Regulation shall not be deemed to require the undertakers to take precautions against contact between a broken line conductor and other auxiliary conductors and earth wires carried on the same support and forming part of the same overhead line.

Supports.

6. Line conductors shall be attached to suitable insulators carried on supports of wood, iron, steel or reinforced concrete. All wooden supports other than oak or hard wood cross-arms shall unless otherwise approved by the Electricity Commissioners be of red fir impregnated with creosote. Special precautions shall be taken to prevent the corrosion of all metal work at or below the surface of the ground.

Factor of Safety of Supports.

7. The supports, in conjunction with stays or struts if provided, shall withstand the longitudinal, transverse and vertical loads due to the ice loadings and wind pressure hereinafter specified without ge and without movement in the ground. In no case shall

the strength of a support in the direction of the overhead line be less than *one-quarter* the required strength in a direction transverse to the line.

The following factors of safety shall apply to each support :—

Material.	Factor of Safety.
Iron or steel . . .	2·5
Wood	3·5
Reinforced concrete . .	3·5

These factors of safety shall be calculated on the assumption that all line conductors cables and wires carried by the supports are at a temperature of 22° F., and have a covering of ice to the radial thickness specified in Regulation 12 (or Regulation 15 according to the voltage) and that together with the supports they are subjected to a wind of 50 miles per hour at right angles to the line, this wind to be taken as exerting a pressure equivalent to 8 pounds per square foot calculated on the whole of the projected area.

The wind pressure on the lee side members of lattice steel or other compound structures, including A and H poles, shall be taken as one-half of the wind pressure on the windward side members. The factor of safety shall be calculated on the crippling load of struts and upon the elastic limit of tension members.

Service Lines.

8. Service lines shall be connected to line conductors at a point of support only and shall be fixed to insulators on consumers' premises. Every part of a service line (other than a neutral conductor connected with earth) which is accessible from a building with the use of a ladder or other special appliance shall be efficiently protected either by insulating material or by other means approved by the Electricity Commissioners.

Erection of Line Conductors at Different Voltages on same Supports.

9. Where line conductors forming parts of systems at different voltages are erected on the same poles or supports adequate provision shall be made to guard against danger to linesmen and from the lower voltage system being charged above its normal voltage by leakage from or contact with the higher voltage system ; and the type of construction shall be subject to the prior approval of the Electricity Commissioners.

Inspection and Maintenance of Lines.

10. Every overhead line, including its supports and structural parts, and electrical appliances and devices belonging to or connected therewith, shall be regularly inspected and efficiently maintained.

Materials used.

11. All materials used shall at the time of erection conform to the specifications of the British Engineering Standards Association and to the Post Office Technical Instructions for the construction of aerial lines for the time being in force, so far as the same are applicable and are not inconsistent with these Regulations.

II.—Specific Regulations.

[*Applicable according to the voltage between line conductors where no part of the system is connected with earth, or according to the voltage to earth where part of the system is connected with earth.*]

A. For voltages not exceeding 650 volts direct current and 325 volts alternating current.

Factor of Safety of Line Conductors.

12. The factor of safety of line conductors shall be 2. The factor of safety shall be based on the breaking load and shall be calculated on the assumption that the line conductors are at a temperature of 22° F. and have a covering of ice to a radial thickness of *three-sixteenths of an inch*, and that they are simultaneously subjected to a wind of 50 miles per hour at right angles to the line, this wind to be taken as exerting a pressure equivalent to 8 pounds per square foot calculated on the whole of the projected area of the ice-covered lines.

The weight of ice is to be taken as 57 pounds per cubic foot.

The elasticity of the metal may be allowed for in calculating the sag for line conductors.

Minimum Height of Conductors.

13. The height from the ground of any line conductor (other than a service line), earth wire, or auxiliary conductor at any point of the span at a temperature of 122° F. shall not, except with the consent of the Electricity Commissioners, be less than 19 feet across a public road or 17 feet in other positions. A height of 15 feet may be adopted in situations inaccessible to vehicular traffic.

Where a service line is carried across or along a carriage
the height of the line from the ground at any part of the ca
way shall not, except with the consent of the Electricity Co
sioners, be less than 19 feet and 17 feet respectively.

Provision to Prevent Danger.

14. Where the voltage to earth exceeds 250 volts direct c
or 125 volts alternating current, precautions should be tak
prevent danger—

(1) from a broken line conductor by the provision of—

(*a*) a neutral or earthed conductor carried contin
from pole to pole, and so arranged in relation
other conductors that in the event of breakage
one of them the line conductor shall make c
with the earthed wire ; or

(*b*) other means approved by the Electricity Commissi

(2) from leakage by the provision—

(*a*) in cases where metal poles are used, of—

(i) an earthed wire, running from pole to pole an
nected to the poles ; or

(ii) a suitable metal framework to support the ins
carrying the line conductors, the framework
insulated from the pole but connected to the n
conductor ; or

(iii) other means approved by the Electricity Co
sioners.

(*b*) in cases where wooden poles are used, of—

(i) a bonding wire connected to the supporting
work of all insulators, the bonding wire termi
at the lowest part of the supporting metal
or

(ii) other means approved by the Electricity Co
sioners.

Where lightning conductors are used or other uninsulate
ductors are run down wooden poles to within 10 feet fro
ground, the precautions for the prevention of danger from l
shall be as for metal poles.

All stay wires other than those which are connected with
by means of a continuous earth wire shall be insulated to p
danger from leakage. For this purpose an insulator shall be
in each stay wire at a height of not less than 10 feet from the g

B. For voltages exceeding 650 volts direct current and 32
alternating current.

Factor of Safety of Line Conductors.

15. The factor of safety of line conductors shall be 2. The factor of safety shall be based on the breaking load and shall be calculated on the assumption that the line conductors are at a temperature of 22° F., and have a covering of ice to a radial thickness of *three-eighths of an inch*, and that they are simultaneously subjected to a wind of 50 miles per hour at right angles to the line, this wind to be taken as exerting a pressure equivalent to 8 pounds per square foot calculated on the whole of the projected area of the ice-covered lines.

The weight of ice is to be taken as 57 pounds per cubic foot.

The elasticity of the metal may be allowed for in calculating the sag for line conductors.

Minimum Height of Conductors.

16. The height from the ground of any line conductor at any point on the span at a temperature of 122° F. shall not, except with the consent of the Electricity Commissioners, be less than the height hereunder stated :—

Voltages not exceeding 66 000 volts.	20 feet.
Voltages exceeding 66 000 volts and not exceeding 110 000 volts.	21 feet.
Voltages exceeding 110 000 volts and not exceeding 165 000 volts.	22 feet.
Voltages exceeding 165 000 volts.	23 feet.

The height from the ground of an earth wire or auxiliary conductor shall not be less than the minimum heights prescribed in Regulation 13.

Provision to Prevent Danger.

17. Adequate means shall be provided to render any line conductor dead in the event of it falling due to breakage or otherwise.

All metal work other than conductors shall be permanently and efficiently connected with earth. For this purpose a continuous earth wire shall be provided and connected with earth at four points in every mile, the spacing between the points being as nearly equidistant as possible, or, alternatively, the metal work shall be connected to an effective earthing device at each individual support. The design and construction of the system of earth connections shall be such that when contact is made between a line conductor and metal connected with earth the resulting leakage current shall not be less than twice the leakage current required to operate the devices which make the line dead.

Road Crossings, &c.

18. Where an overhead line is erected along or across a pub road or canal or across a railway all wires including earth wires a auxiliary conductors shall be placed at the appropriate height fr the ground specified in Regulation 16 for line conductors, and t following additional precautions shall be taken to prevent danger :

(1) In the case of a line erected *along* a public road or canal (within 50 feet thereof) there shall be provided—

(*a*) duplicate insulators supporting the conductors ; or

(*b*) a device to ensure that in the event of a line conduct falling it shall be put to earth ; or

(*c*) other means approved by the Electricity Commissione

(2) In the case of a line erected *across* a public road, canal railway there shall be provided—

(*a*) duplicate insulators for supporting the line conductor a a device to ensure that in the event of a line cc ductor falling it shall be put to earth ; or

(*b*) duplicate insulators supporting duplicate conductors t at intervals not exceeding five feet ; or

(*c*) other means approved by the Electricity Commissione

Danger Notices.

19. Supports shall be numbered consecutively and each supp shall have a danger notice of a permanent character securely fix to it. Adequate provision shall also be made to prevent unauth ised climbing.

These Regulations are made subject to the power of the El tricity Commissioners to make such further or other Regulatic as they may think expedient and shall apply to any overhead li erected by authorised undertakers :

Provided that these Regulations shall not apply to any overhe lines in existence at the date hereof and constructed and maintai by authorised undertakers under and in accordance with the p visions of any prior Regulations for overhead lines made by t Board of Trade or the Electricity Commissioners.

Signed by order of the Electricity Commissioners this 16th d of April, 1928.

R. T. G. French,

Secretary to the Electricity Commission

ELECTRICITY COMMISSION.

EXPLANATORY MEMORANDUM *on the Revised Code of Overhead Line Regulations (El. C. 53A) made by the Electricity Commissioners and on matters relevant thereto.*

The Electricity Commissioners have recently reviewed the Code of Overhead Line Regulations (El. C. 39) adopted by them in the latter part of 1923, with the object of determining whether relaxations consistent with the maintenance of a reasonable degree of safety to the public could be made for the purpose more particularly of facilitating the development of overhead distribution at the lower voltages in rural areas.

Due regard has been given to various representations on this matter which have been made to the Commissioners from time to time on behalf of the Electricity Supply Industry, and the technical aspects have formed the subject of conferences between the Commissioners and Electrical Engineers who have had considerable experience in the erection of overhead lines in rural districts and elsewhere. The Commissioners have also conferred with the Postmaster-General on the question of the relaxation of his requirements as to protection between telegraph or telephone lines and electric supply lines.

As a result, the Commissioners have adopted a revised Code of Overhead Line Regulations (El. C. 53) with effect as from 16th April, 1928, and the following explanatory notes dealing with the various relaxations and with other relevant questions have been prepared for the information of the Electricity Supply Industry.

REGULATION 1 (*Materials for Line Conductors*).

This Regulation remains unaltered, but it may be noted that the "other materials" for line conductors which have already been approved by the Electricity Commissioners in certain cases include steel-cored aluminium, steel, cadmium copper and other appropriate alloys of high tensile strength.

REGULATION 3 (*Minimum Size of Line Conductor*).

In view of the relaxation which has been made in the assumed ice loading on line conductors (Regulations 12 and 15) and in guarding requirements (Regulation 14), the minimum size of copper conductor (other than service lines) is in future to be No. 8 S.W.G. or the nearest equivalent section of stranded conductor (being not less than

No. 8 S.W.G.). The minimum size of lines in general (other than service lines) is to be such that the actual breaking load shall be not less than 1 237 lb.

REGULATION 6 (*Supports*).

Under this Regulation, as amended, the Commissioners will be prepared in special cases to consent to the use of wooden poles other than of red fir, provided that suitable precautions are taken in the felling, selection and treatment of the timber.

REGULATION 7 (*Factor of Safety of Supports*).

After consultation with the Air Ministry, the National Physical Laboratory and the British Electrical and Allied Industries Research Association on the questions of climatic conditions, wind velocities and wind pressures, the Commissioners have decided to retain the same wind pressure and the same factors of safety as are prescribed by the existing Code in respect of supports and also of line conductors. The wind pressure on the supports alone has been shown to vary with different types of support, but is usually only a small proportion of the total load on the supports.

The Commissioners have concluded, however, that the relaxed conditions with regard to the assumed ice loading on line conductors (Regulations 12 and 15) will enable supports of suitable size and strength, but of less expensive construction than hitherto, to be adopted consistently with securing the safety of the public. An enquiry is being continued into the factor of safety of reinforced concrete supports.

With regard to the foundation of supports, the Regulation now requires that the supports shall withstand the specified ice loadings and wind pressure *without movement in the ground.* As the working load under the Revised Code will constitute a greater proportion of the ultimate strength of the supports than under the prior Code, it will be more particularly necessary to pay attention to the foundations of wooden poles, which will require the addition of cross members or "kicking blocks" (excepting in the case of poles of small sizes) *in order that the foundation may be as strong as the pole itself.*

REGULATION 8 (*Service Lines*).

The requirement for the protection of persons working on the outside of buildings may be generally assumed to involve the covering of all live conductors with durable insulating material for so much of their length as lies within 6 feet of the building.

REGULATION 9 (*Erection of line Conductors at Different Voltages on same Supports*).

Although the construction of lines at different voltages on the same supports was not precluded under the prior Code, the Commissioners have considered it desirable to include a new Regulation dealing specifically with this matter. The Commissioners will be prepared to approve of types of construction under this Regulation which make adequate provision for avoiding danger to linesmen working on the lines and for preventing contact between the higher and lower voltage systems.

REGULATION 12 (*Factor of Safety of Line Conductors*).

The Commissioners have made a relaxation in the assumed ice loading on lower voltage lines from one-quarter of an inch to *three-sixteenths* of an inch, but, as previously indicated, have retained the provisions of the prior Code as to wind pressure and factor of safety. The assumed ice loading and unaltered factor of safety will permit of line conductors being strung to a tension which is at least *as high as may profitably be used* and is consistent with the tension when the line withoutthe assumed ice loading is subjected to a wind of gale force equivalent to a pressure *of 20 lb. per sq. foot.*

REGULATION 13 (*Minimum Height of Conductors*).

The minimum height from the ground of lower voltage line conductors has been reduced from 20 feet to 19 feet across public roads ; to 17 feet along public roads and in other positions ; and to 15 feet in situations inaccessible to vehicular traffic.

The minimum height of service lines has been reduced from 20 feet to 19 feet across carriage-ways and to 17 feet along carriage-ways.

REGULATION 14 (*Provision to Prevent Danger*).

Provided that one of the conductors is properly connected to earth at the point of supply and that the lines are so arranged that the earthed conductor is placed below the other conductors, no other guarding on lower voltage lines will be required.

If the conductors are arranged in a vertical plane with the earthed conductor placed lowermost, the protection afforded is adequate. If the conductors are not so arranged, then the earthed conductor, which must still be erected in the lowermost position, should be staggered from right to left of each succeeding support so as to afford

a reasonable certainty that a broken conductor will make contact with the earthed conductor.

With the reduction in the minimum height from the ground afforded by Regulation 13, many lower voltage lines will be able to pass *beneath* other lines such as telegraph or telephone wires. The Commissioners are in a position to state that in such cases the requirements of the Postmaster-General for guard wires will be satisfied if a single earthed wire is run above the power wires for the length of the span.

The Postmaster-General has further agreed to a relaxation in the Post Office Memorandum T.E. 80 (protection of telegraphs from contact with low and medium pressure power circuits) by modifying his present requirement of 4 feet clearance between low and medium pressure power wires and telegraph lines to the extent of allowing a minimum of 2 feet if the power line supports are placed in such a position with respect to Post Office wires that there shall be no danger to men working on the Post Office poles and that there shall be no appreciable difference in sag under the worst conditions of ice loading.

The requirement of a bonding wire connected to the supporting metal work of all insulators used with wooden poles appears to be necessary in the interest of authorised undertakers; and a suitable earthing of metal poles is likewise necessary. These features are therefore retained in the new Regulations.

Where lightning conductors are used with wooden poles, it is desirable that to a height of 10 feet from the ground they should either be insulated or connected to a continuous earth wire having an efficient earth connection. The Commissioners have also concluded that where stay wires are used in conjunction with wooden poles, it is necessary that insulators should be interposed in the stay wire. Such insulators would not be necessary in stay wires fixed to metal poles which are protected from leakage in accordance with Regulation 14 (2).

Regulation 15 (*Factor of Safety of Line Conductors*).

The Commissioners have made a reduction in the assumed ice loading on higher voltage lines from one-half of an inch to *three-eighths* of an inch, but, as previously indicated, have retained the provisions of the prior Code as to wind pressure and factor of safety. The relaxation affords a reasonable measure of relief from the original requirement.

REGULATION 16 (*Minimum Height of Conductors*).

In the case of higher voltage line conductors, the Commissioners have decided to retain the provisions of the prior Code as to minimum height above ground. The Regulation has been amplified, however, to deal with the minimum height of associated earth wires or auxiliary conductors.

General Observations.

The combined effect of the preceding relaxations in the case of lower voltage lines will be found to be such as to enable supports of reduced *diameter* as well as of reduced *length* to be employed. For example, making due allowance for the reduction in the height of a lower voltage line above the ground from 20 feet to 17 feet (Regulation 13), a wooden pole having a diameter of only $7\frac{1}{4}$ inches at a distance of 5 feet from the butt will hereafter be needed where previously a diameter of $8\frac{1}{4}$ inches would have been required under the prior Code.

As a further means of facilitating the extension of overhead distribution in rural areas, the Commissioners are prepared, under their Regulations for securing the safety of the public and for ensuring a proper and sufficient supply of electrical energy, to give consent in special cases to a voltage variation within the limits of plus 4 and minus 8 per cent. of the declared voltage on rural lines for a provisional period pending the completion of the distribution system and its full measure of interconnection. After such provisional period, the variation can reasonably be limited to the normal requirement of plus or minus 4 per cent.

Procedure.

The Commissioners suggest that authorised undertakers should take a reasonably long view of the probable development of low voltage overhead distribution in their area and should, where practicable, make application to the Minister of Transport for a consent to more comprehensive proposals than hitherto instead of making repeated applications for individual lines, thus saving time and expense.

With the view of expediting the consideration of applications, the procedure formerly adopted by the Board of Trade and continued by the Commissioners on behalf of the Minister of Transport, of referring all overhead line applications to the Postmaster-General for his observations will, by agreement between the Departments, be abandoned as from the issue of the Revised Regulations. The

Commissioners suggest, however, that in all cases where it is intended to run high voltage or extra high voltage overhead lines for an appreciable distance parallel with Post Office overhead routes, the authorised undertakers concerned should adopt the general practice of conferring with the Post Office engineers in their district prior to applying for consent to such overhead lines, so that the possibility of inductive interference may be considered before the route is actually fixed. It will, of course, still be necessary for the undertakers to give statutory notice to the Postmaster-General in compliance with Section 14 of the Schedule to the Electric Lighting (Clauses) Act, 1899.

With the concurrence of the Minister of Transport, the existing Memorandum of particulars required in connection with proposals to erect overhead lines (Form El. C. 34) has been modified with the view of simplifying procedure. The main alterations in the Revised Memorandum (El. C. 53B) are as follows :—

(*a*) Legible tracings or prints taken from 6-inch Ordnance maps may now be submitted in lieu of the maps themselves; and in cases relating to overhead lines at extra high voltage, duplicate maps will not in future be required.

(*b*) Where an undertaker has submitted full technical details with one application and consent is subsequently sought to the construction of further overhead lines to the same specification, it will not be necessary to resubmit full technical details, but only to furnish certain limited particulars.

(*c*) A form of communication which the undertakers should send to the Local Authority or County Council when proposing to apply to the Minister for consent to erect overhead lines has been drawn up and is included in the Revised Memorandum.

Electricity Commission,
Savoy Court,
Strand, W.C. 2, *April*, 1928.

APPENDIX II.

ELECTRICITY (SUPPLY) ACTS, 1882 TO 1926. [El. C. 53B.]

OVERHEAD LINES.

MEMORANDUM *setting forth the information to be submitted in connection with applications by Authorised Undertakers for the consent of the Minister of Transport to the placing of electric lines above ground.*

1. An application for the consent of the Minister of Transport to the placing of an electric line above ground should be formally addressed to The Secretary, Ministry of Transport, Whitehall Gardens, S.W. 1, but may be delivered direct to the Office of the Electricity Commissioners who advise the Minister in connection with the technical aspects of all overhead line proposals.

2. The application must be accompanied by the technical and other particulars set out in the Schedule appended to this Memorandum duly signed on behalf of the undertakers.

3. Where the electric lines forming the subject of any application are to be constructed in accordance with details already submitted with a prior application to which the consent of the Minister has been given, it will only be necessary for the undertakers to submit certain details as indicated in the Schedule and to complete and sign the Certificate at the end of the Schedule.

4. The undertakers should serve a notice of their application as nearly as may be in the form set out in the next page of this Memorandum, together with a description of the nature and position of the proposed lines, on the local authorities in whose districts the lines are to be placed and on the County Council in cases where a county bridge or a main road vested in such Council is concerned. The local authorities in England and Wales are Borough Councils, Urban District Councils and Rural District Councils. The local authorities in Scotland are Police Commissioners, Gas Commissioners, Town Councils and County Councils.

5. In making application to the Minister, the undertakers should give the date of the service of the above-mentioned notice, and a list of the authorities upon whom the notice has been served. Where

possible; the undertakers should submit evidence showing whether or not the authorities desire to be heard by the Minister.

6. Where it is proposed to place an electric line across any land (other than a street or public bridge) or across or along any railway, canal, inland navigation, dock or harbour, the undertakers should state whether wayleaves have been agreed with the owner and occupier of the land or with the owners of the railway, canal, inland navigation, dock or harbour as the case may be.

7. Attention is drawn to the revised Code of Overhead Line Regulations of the Electricity Commissioners (Form El. C. 53) and to the Explanatory Memorandum (El. C. 53A) issued in connection therewith; and to the provisions relating to the approval of plans and works contained in Section 14 of the Schedule to the Electric Lighting (Clauses) Act, 1899, or corresponding provision in the Undertakers' Act or Order.

Ministry of Transport,
6 Whitehall Gardens,
S.W. 1, *April*, 1928.

Form of Notice.

ELECTRICITY (SUPPLY) ACTS, 1882 TO 1926.
(Title of Order or Special Act.)

Sir,

I beg to inform you that the (*insert name of applicants*) have made an application to the Minister of Transport for consent to the placing of electric lines above ground for the purposes of the abovementioned Order (or Special Act), and in this connection desire to draw the attention of your Council to the provisions of Section 21 of the Electricity (Supply) Act, 1919, as amended by Section 50 of and the Sixth Schedule to the Electricity (Supply) Act, 1926.

The Acts in question provide that where the consent of the Minister of Transport is obtained to the placing of any electric line above ground in any case, the consent of the local authority (including a County Council) shall not be required, anything in the Electric Lighting Acts or in any Order or Special Act relating to the undertaking to the contrary notwithstanding, but the Minister of Transport before giving his consent shall give the local authority and (where it is proposed to place the line along or across any county bridge or any main road vested in a County Council) the County Council an opportunity of being heard.

A description of the nature and position of the proposed lines so far as they affect your Council is enclosed herewith and I shall be

glad to learn at your earliest convenience whether (*insert name of applicants*) may notify the Minister that your Council do not desire to be heard in connection with the application.

(To be signed on behalf of the Applicants.)

Schedule of Particulars.

NOTE.—[illegible] *items* (1) *to* (7) (*d*) *are required in every case. With regard* [illegible] *attention is drawn to the Certificate at the end of this Schedule.*

(1) An Ordnance map on a scale of six inches to the mile (or a tracing or print therefrom giving appropriate reference to the Ordnance map) must be supplied showing :—

(*a*) The proposed route of the line with positions of the terminal, intermediate and angle supports, and of the "earth" plates. Any underground portion of the line should be shown in distinctive colour.

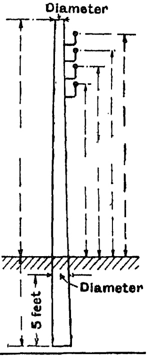
(*b*) Any existing overhead lines, whether for power, lighting, traction, telegraph or telephone purposes, in the immediate vicinity of the proposed transmission lines.

(2) Working voltage	Volts.
(3) Is supply by direct or alternating current ?	
(4) If by alternating current, state number of phases and frequency . . .	Phase. Cycles.
(5) Maximum amount of energy which the line is designed to transmit, in kilowatts	
(6) Total route length of overhead line, in yards	
(7) Conductors :—	
(a) Number	(a)........................
(b) Material used	(b)........................
(c) Solid or Stranded	(c)........................
(d) Sectional area of each conductor and when stranded, the number and diameters of wires	(d)........................
*(e) Height of lowest conductor (or earth or neutral wire if forming part of the conducting system) above ground at pole, in feet	(e)........................
*(f) Sag of lowest conductor (or earth or neutral wire if forming part of the conducting system) at temperature of 122° Fahrenheit on maximum span, in feet	(f)........................
*(g) Minimum height above ground of lowest conductor or wire between poles on maximum span, in feet .	(g)........................
*(h) Breaking load of materials in tons per square inch	(h)........................
*(i) Elongation of conductor in length of 10 inches on breaking, per cent. .	(i)........................

*(8) Earth Wire (not forming part of the conducting system) or auxiliary conductor :— (a) Size . . . . (b) Description . . . . . . (c) Height above ground at pole, in feet	(a)...... (b)...... (c)......
*(9) Span between poles or other supports :— (a) Average span, in feet . . . (b) Maximum span, in feet . .	(a)...... (b)......
(10) Poles :— (a) Class of pole to be used, *i.e.* Wood, Steel Tubular, Lattice or other material. See paragraph (13) below . (b) Diameter of pole at top, in inches . (c) Diameter of pole at 5 feet from butt, in inches . . . . . (d) Depth of pole in ground, in feet . (e) Overall length of pole, in feet . (f) If wooden poles are used, the nature of the timber . . . . (g) If steel tubular poles are used, the thickness of metal, in inches . (h) Breaking stress of steel used in poles, in tons per square inch . .	(a)...... (b)...... (c)...... (d)...... (e)...... (f)...... (g)...... (h)......
*(11) Type of automatic protective device .	
*(12) Earth plates :— (a) Type . . . . (b) Dimensions . . . . . . (c) Metal . . . . . . (d) Number proposed	(a)...... (b)...... (c)...... (d)......

*(13) A drawing (scale to be stated and to be not less than one-half inch to the foot) of each type of pole proposed to be used, with dimensions as in Fig., must be supplied showing :—

(a) Details of stays and struts.
(b) Cross-arms.
(c) Insulators.
(d) Arrangement of conductors and their sizes indicated against each insulator.
(e) Safety arrangements at road, railway and canal crossings.
(f) Earth wire and earth plates.



If steel lattice masts, reinforced concrete poles or supports of special design are proposed to be used, stress diagrams with detailed calculations must be submitted in addition to the drawing referred to above.

The particulars set out against items......of the above Schedule relate to the overhead lines forming the subject of the application made on ......by the......

(Signed......

Electrical Engineer to the Undertakers.

* Certificate.

(In cases where details (7) (*e*) to (13) submitted with a prior application are applicable.)

I HEREBY CERTIFY that the overhead lines forming the subject of this application will, so far as items (7) (*e*) to (13) of the preceding Schedule are concerned, be constructed in accordance with the details submitted in connection with a prior application made on......................to which the consent of the Minister of Transport was given on......................................

(Signed)...
Electrical Engineer to the Undertakers.

APPENDIX III.

POST OFFICE ENGINEERING DEPARTMENT.
[E. in C. 231.]

MEMORANDUM *on Protection of Overhead Telegraph or Telephone wires at Crossings of High or Extra High Pressure overhead Power Lines.*

THE Electricity Commissioners' Regulations for Overhead Power Lines stipulate that where a line conductor crosses over or under or is in proximity to any other overhead wire, precautions shall be taken by the undertakers to prevent contact, due to breakage or otherwise, between the line conductor and the other overhead wire, or between the other wire and the line conductor.

Where the power circuit is classified as high or extra high pressure it is the practice to arrange for either the power wires or the telegraph and telephone wires to be placed underground at crossings.

Where the Post Office circuits are local and there is little loss in efficiency by placing them underground this method of protection will be adopted (otherwise the power line should be placed underground for the requisite distance).

In cases where there are serious objections to either the telegraph or the power line being placed underground the method shown in the annexed sketch will be adopted, the protection taking the form of a substantial cradle guard. The power line and the guard should comply with the following conditions:—

(1) The routes must cross at right angles and continue at right angles for a distance of not less than 20 yards on each side of the crossing. In difficult cases, however, a deviation up to 30 degrees from the right angle will be accepted for a straight-through crossing.

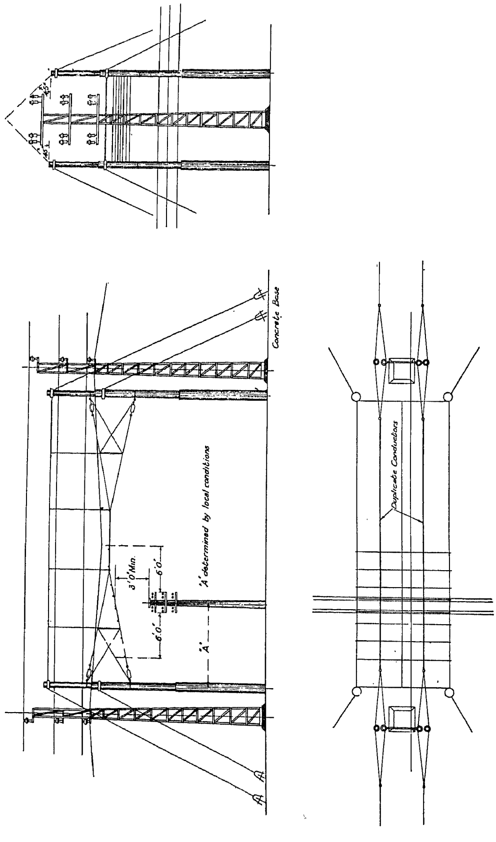
(2) The power lines must cross above the telegraphs or telephones.

(3) Duplicate conductors lashed every 5 feet and terminated on separate insulators must be provided for each power wire at each end of the crossing span; alternatively a single conductor will be accepted, provided that it is stranded and used with duplicate insulators, bridles, and the earthing device specified by the Electricity Commissioners:—

(4) The poles or structures supporting the power wires at the crossing span must be sufficiently strong to serve as terminals should the wires in adjacent spans break.

R. No. 117

GUARD, CRADLE INDEPENDENT.



The deflection of the structures under such conditions must be less than would permit the power conductors to sag on the guard.

The poles should preferably be of steel or iron but if of wood all metal fittings shall be connected to earth by low resistance conductors as specified for the guard under condition (5).

(5) The independent poles supporting the cradle guard may be of wood, iron, steel or reinforced concrete. The clearance between guard and power conductors must be sufficient to prevent contact under the worst possible conditions, otherwise than by breakages of conductors.

The top or outside wire on each side of the independent cradle guard shall be so arranged that lines drawn upwards from them towards the centre at an angle of 45 degrees will totally enclose the power wires together with any telephone control or other wire belonging to the power system.

The guard to be made of wire of not less than 7/14 S.W.G. galvanised steel or hard drawn copper.

The cradle will be cross-laced every two feet above the telegraph wires to a distance of 6 feet beyond the wires on each side.

The guard to be connected to earth at each end of the crossing. The resistance of guard to earth shall not exceed 1 ohm or 60/A ohms, whichever is the smaller value. (A = max. current of system.)

The earth and earth connections must be capable of carrying the maximum current which can flow to earth in the event of a contact between a power conductor and the guard.

In the case of wood poles, the earth connection shall be so grooved into the pole that there will be no danger of the wire being tampered with.

(6) The clearance between the guard and the telegraphs must not be less than 3 feet.

(7) The poles, structures and wires of the power lines must be constructed with the factors of safety laid down in the Electricity Commissioners' Regulations for Overhead Lines.

(8) The structure supporting the power line crossing span to be placed in positions free from risk of damage by traffic.

(9) Alternatively to the provision of an independent guard, the erection of a cradle guard on the power circuit supports will be accepted, providing the structures are of steel or iron, very stable in design and that other conditions are satisfactory.

(10) Detailed drawings and plan to be submitted to Engineer-in-Chief, Post Office, for approval, the erection and maintenance to be to the satisfaction of the Engineer-in-Chief.

APPENDIX IV.

POST OFFICE ENGINEERING DEPARTMENT. [T.E. 80.]

MEMORANDUM *on Protection of Telegraphs from Contact with Low and Medium Pressure Power Circuits (excluding Traction Circuits).*

1. The Electricity Commissioners' Regulations for Overhead Power Lines stipulate that where a line conductor crosses over or under or is in proximity to any other overhead wire, precautions shall be taken by the undertakers to prevent contact, due to breakage or otherwise, between the line conductor and the other overhead wire, or between the other wire and the line conductor.

2. For the purposes of this Memorandum the expression "telegraphs" includes all telegraph and telephone conductors and also stay wires; and the expression "power circuit" means any continuous current * or alternating current * power circuit (other than a traction circuit) so arranged that the maximum pressure between any two conductors of a circuit entirely insulated from earth or between any conductor and earth, in the case of a circuit earthed at the power station, sub-station or transformer, does not exceed 650 volts.

3. When the pressure to earth, or between any two conductors of an unearthed system, does not exceed 60 volts A.C. or 120 volts C.C., no guarding is required.

4. When the pressure to earth, or between any two conductors of an unearthed system, exceeds 60 volts A.C. or 120 volts C.C., guarding is required :—

(*a*) at each point of crossing or overhanging ;

(*b*) in the case of parallel lines, where the vertical distance between any telegraph and any power wire exceeds the horizontal distance † (*see* Fig. 1),

and the approved arrangement and the scope of each are as follows :

* In further references to "continuous current" and "alternating current" the abbreviations "C.C." and "A.C." respectively are used.

† This corresponds to the 45° rule applied to electric tramway and trackless trolley systems.

Arrangement.	Scope. System.	Maximum Pressure to Earth or between Conductors of Unearthed Systems, volts.
I. The disposition of permanently earthed power conductors * so that they act also as guard wires.	A.C. C.C.	250 650
II. The use, for potential conductors, of wires insulated with an approved weatherproof covering † (bare wires being permitted for permanently earthed conductors).	A.C. C.C.	250 650
III. The use of any form of covered power conductors (including lead-covered cables) supported by earthed bare suspending wires (including neutral conductors).	A.C. or C.C.	650
IV. The use by the Post Office of insulated conductors for the telegraphs, other than the telephone trunk circuits.	A.C. C.C.	250 650
V. The provision of independent guard wires.	A.C. or C.C.	650

5. The details of the normal requirements, which in some cases depend on the design of the power circuit and its position relatively to the telegraphs, are set forth in the following pages; but, occasionally, *e.g.* in very exposed situations, it is necessary to impose more stringent requirements.

6. In all cases, *i.e.* irrespective of the pressure of the power circuit, a clearance of 4 feet should normally be given, but where it would be difficult or costly to provide more than 3 feet this will be agreed. Further, at crossings a clearance of 2 feet will be agreed, at the discretion of the Post Office Sectional Engineer, in cases where the power line supports are placed in such a position with respect to Post Office wires where there will be no appreciable difference in sag with changes of temperature or under the worst conditions of ice loading, and that there is no danger to men working on the P.O. poles. If the P.O. line is not fully developed additional clearance

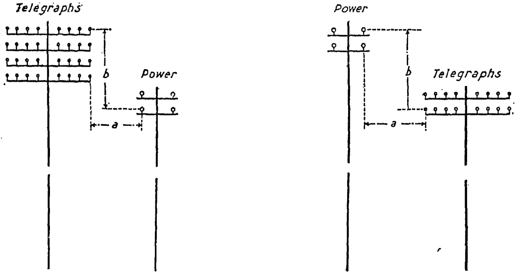
* The term "earthed (power) conductor" as used in this Memorandum means "permanently earthed" and includes "neutral conductor."

† Other braided conductors, with or without rubber, fall under arrangements I., III. and V.

may be necessary at the outset to provide for the ultimate conditions.

7. Telegraphs endangered by a power circuit are equipped with internal protective devices, *i.e.* fuses and heat coils, and the erection of a power circuit may involve the provision of such devices.

8. When the necessity for protection arises from the erection of telegraphs, *i.e.* the telegraphs are "second comer," the Postmaster-General as a concession will bear the cost of any fuses and heat coils installed and also the cost of the most economical method of guarding having regard to the ultimate conditions; but in all other cases the whole cost of protection falls upon the undertaker.



GUARD WHEN "a" IS LESS THAN "b".

FIG. 1.

(I) Permanently Earthed Conductors arranged to act as Guard Wires.

9. The earthed conductor shall consist of copper wire, not lighter than No. $11\frac{1}{2}$ S.W.G., which shall be earthed at one point only, that is, at the generating station, sub-station, or transformer. The earth connection must be permanent and the electrical continuity of the wire must be maintained at all times.

(A) Telegraphs Above a Power Circuit.

(*i*) *Crossings at Angles greater than* 30°.

10. An earthed conductor shall be erected above the potential conductors—Figs. 2, 3 and 4.

11. Where a vertical formation is used for the power wires as in

Fig. 2 an earthed conductor shall be erected above the potential conductors in the same vertical plane with a minimum clearance of 8 inches to the highest potential wire.

12. Where the power wires are erected with any other than the vertical formation an earthed conductor shall be erected uppermost in such a position that lines drawn from it to the outermost potential wires will not make a greater angle than 45° with the vertical. *See* Figs. 3 and 4.

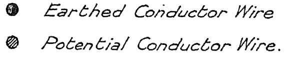


FIG. 2.

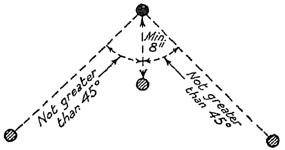


FIG. 3.

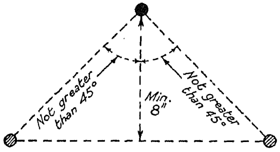


FIG. 4.

(ii) Crossings at Angles less than 30° and Parallel Lines.

13. Where the angle of crossing is less than 30° two earthed conductor wires shall be provided if in the opinion of the Post Office Sectional Engineer the conditions as regards danger are not satisfactorily met by the provision of one earth guard wire. Figs. 5, 6, 7 and 8.

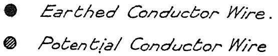
Cross-lacing may also be required if there is direct overhanging, and this should be provided by means of wire placed at intervals of

not more than 6 feet for such a distance as may be stipulated by the Post Office Sectional Engineer.

(B) Telegraphs Below a Power Circuit.

(i) Crossings at, or approximately at, Right Angles.

14. The earthed conductors shall be erected as shown in Fig. 9, which indicates three variations in their position relatively to the potential conductors.



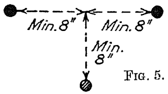


Fig. 5.

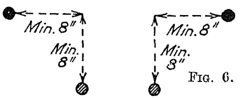


Fig. 6.

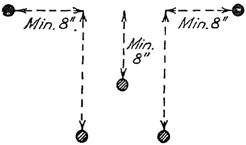


Fig. 7.

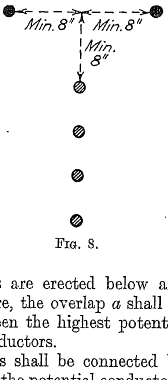


Fig. 8.

15.—(1) When the earthed conductors are erected below any potential conductor, including a switch wire, the overlap a shall be greater than the vertical distance b between the highest potential conductor and the plane of the earthed conductors.

(2) In all cases the earthed conductors shall be connected by cross wires of the same gauge passing under the potential conductors, the cross wires being spaced at intervals of not more than 6 feet for a distance of 18 feet on each side of the crossing, except where there is a pole within 18 feet, in which event the cross wires need not extend beyond the pole.

(ii) Diagonal Crossings and Overhangings.

16. Fig. 9 applies, but the earthed conductors will be cross-laced at intervals of 6 feet, for such a distance as may be stipulated by the Post Office Sectional Engineer.

(iii) Parallel Lines.

17. Fig. 9 applies, but the earthed conductors will be cross-laced at intervals of 6 feet throughout the section affected, *i.e.* falling within the scope of paragraph 4 (*b*).

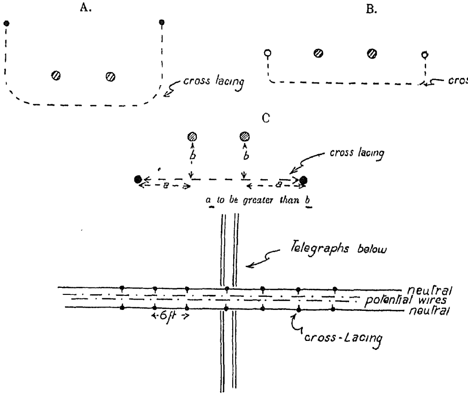


Fig. 9.

(II) Power Conductors Insulated with Approved Weatherproof Covering.

18. Conductors covered with a satisfactory weatherproof insulating material similar to that used by the Post Office at power crossings—*see* (IV) *below*—will be accepted as affording adequate protection, provided that the pressure to earth of the power circuit does not exceed 250 volts A.C. or 650 volts C.C. Further, within these limits of pressure, bare wire may be used for permanently earthed conductors.

The covered conductor must withstand specified electrical tests of a searching character.

These tests, together with the significant clauses in the Post Office specification for the type of covered conductor referred to are given in Appendix I. Conductors covered with this type of insulation can be obtained from the leading British makers of insulated wire and, if purchased to the specification from manufacturers approved by the Post Office, will be accepted as satisfactory, subject to the proviso that the Postmaster-General reserves the right in any particular case to ascertain by tests on samples of the wire whether the specification is being complied with. Should the tests on the samples show that the wire is not to standard, approval of its use will be withheld.

Varnished cambric will be accepted as an alternative to paper in the make up of the insulating covering.

(III) Covered Power Conductors Supported by Earthed Bare Suspending Wires.

19. Any covered power conductor will be accepted as satisfactorily guarded if it is suspended from an efficiently earthed bare wire, by means of uninsulated ties. The distance between such ties shall not exceed 2 feet, and the suspending wire shall be earthed at both ends and, if necessary, at intermediate points, so that the distance between any two earth connections does not exceed 200 yards.

(IV) Insulated Conductors for the Telegraphs.

20. When the pressure of the power circuit does not exceed 250 volts A.C. or 650 volts C.C., the Postmaster-General is prepared to erect or substitute insulated wire, instead of bare wire, for the telegraphs, provided that a small number of telegraph wires is concerned, the route is not likely to grow, and that the efficiency of the circuits will not be impaired.

Generally, the arrangement is not applicable to Post Office lines carrying telephone trunk circuits.

(V) Independent Guard Wires.

21. Guard wires should be, in general, of galvanised steel, minimum gauge No. 8 S.W.G. or 7/16 S.W.G., but in manufacturing districts where such wire is liable to rapid corrosion, bronze or hard drawn copper wires of equivalent strength should be used.

The supports for the guard wires should be rigid and of sufficient strength for their purpose, and at each support each guard wire should be securely bound in or terminated.

Each guard wire, including all the longitudinal wires forming a cradle guard, must be well earthed at both ends, and at intervals of not more than 200 yards.

Each Earth should be made by means of a permanent connection to a water main, or by means of a substantial cast-iron earth plate fitted with a strand of copper wire of sufficient length to admit of the joint being made above ground. When first erected the resist-

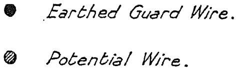


Fig. 10.

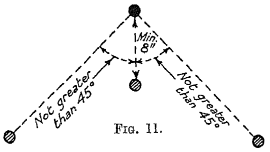


Fig. 11.

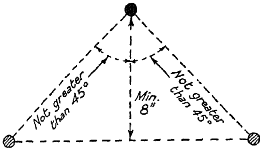


Fig. 12.

ance to earth of the guard wires should be tested, and periodical tests should be made by the undertaker to prove that each earth connection is efficient.

(A) Telegraphs Above a Power Circuit.

(*i*) *Crossings at Angles greater than* 30°.

22. Where a vertical formation is used for the power wires, as in Fig. 10, a guard shall be erected above the power wires in the same

vertical plane with a minimum clearance of 8 inches to the highest power wire.

23. Where the power wires are erected with any other than a vertical formation a guard wire shall be erected uppermost in such a position that lines drawn from it to the outermost potential wires will not make greater angles than 45° with the vertical plane. *See* Figs. 11 and 12.

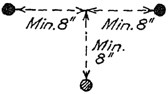


FIG. 13.

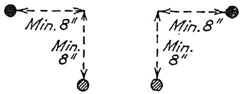


FIG. 14.

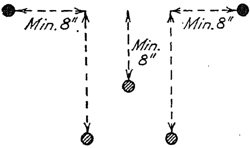


FIG. 15.

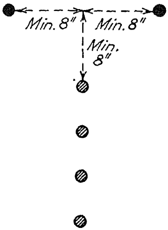


FIG. 16.

(ii) Crossings at Angles less than 30° *and Overhangings.*

24. Where the angle of crossing is less than 30° two earthed guard wires shall be provided if in the opinion of the Post Office Sectional Engineer the conditions as regards danger are not satisfactorily met by the provision of one earthed guard wire. Figs. 13, 14, 15 and 16.

Cross-lacing may also be required if there is direct overhanging, and this should be provided by means of wire placed at intervals of not more than 6 feet for such a distance as may be stipulated by the Post Office Sectional Engineer.

(B) TELEGRAPHS BELOW A POWER CIRCUIT.

(i) Crossings at, or approximately at, Right Angles.

25. An earthed cradle guard (Fig. 17) shall be erected between the power circuit supports.

(ii) Diagonal Crossings and Overhangings.

26. Fig. 17 applies, but the cradle guard will be provided for such a distance as may be stipulated by the Post Office Sectional Engineer.

(iii) Parallel Lines.

27. Fig. 17 applies, but the cradle guard will be provided throughout the section affected, *i.e.* falling within the scope of paragraph 4 *(b)*.

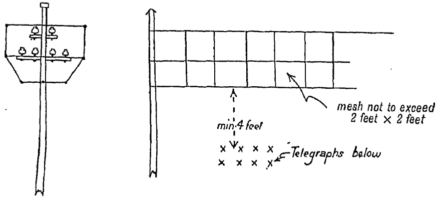


Fig. 17.

APPENDIX I.

SIGNIFICANT CLAUSES OF THE P.O. SPECIFICATION FOR CONDUCTORS INSULATED WITH APPROVED WEATHERPROOF COVERING.

General.

The completed wire shall consist of a hard drawn copper wire insulated with two layers of impregnated paper covered with a layer of cotton lappings and cotton braiding impregnated with a weatherproof composition.

Dielectric and Weatherproof Covering.

The two [illegible] in opposite directions [illegible] approximately 5 turns in 3 inches. The paper shall be manilla of approximately ·280 inch wide and ·006 inch thick, treated with linseed oil.

The cotton lappings and braiding shall be thoroughly impregnated with a mixture composed of approximately :—

Red Lead	72 parts by weight.
Linseed Oil	16 ,, ,,
Paraffin Wax	12 ,, ,,

The paraffin wax before being used shall be rendered anhydrous by being heated to a temperature of 300° to 350° F. until all water is expelled.

The completed wire shall be finally passed through a bath of anhydrous paraffin wax at a temperature of 150° to 200° F., so that the covering is left with a fairly smooth and glossy surface.

INSULATION TESTS.

The completed wire shall pass the following tests not less than 14 days after anufacture :—

(a) A piece of tinfoil 6 inches in length will be lapped closely round the wire at any points selected by the Inspecting Officer. An insulation test made between the conductor and the tinfoil, using 1 000 volts for the test, shall give a resistance of not less than 100 megohms.

(b) A similar test to (a), made after the coil has been immersed in water for 24 hours, shall give a minimum resistance of 2 megohms.

(c) Insulation tests will be made between bare wire closely lapped round the exterior of the completed wire and similar bare wire lappings 6 inches distant. Three laps of the bare wire will be made at each point. The insulation shall be not less than 10 000 megohms when tested with 1 000 volts.

(d) A similar test to (c), made after the coil has been immersed in water for 24 hours, shall give a minimum resistance of 100 megohms.

GENERAL INDEX.

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